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INTRODUCTION TO ELECTRICAL PRINCIPLES

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1. INTRODUCTION TO TELECOMMUNICATIONS.

1.1 Telecommunication services cover a wide field and it is necessary to have some knowledge of the main aspects of the telecommunication system. Broadly speaking, telecommunications is concerned with providing facilities for the transmission of intelligence in a variety of forms, including:

:: Telephone conversations.

:: Telegraph and data information.

:: Radio broadcasts.

:: Television broadcasts.

1.2 TELEPHONE SERVICES. The aim of a telephone service is to provide facilities which enable any customer to converse with another customer, either within Australia or overseas.

In general, a basic telephone system can be divided into three main elements:

:: The telephone instrument in the home or business offices of the customer. The equipment at these locations is referred to as customers equipment.

:: Centres to which customers are connected, and where the necessary connections between customers are made, are referred to as switching centres or exchanges. The switching equipment therein is classed as internal plant.

:: The wires, either overhead on poles (open wire lines) or cables (usually underground), which connect the customer to the telephone exchange. The open wire lines and cables are referred to as external plant.

1.3 Due to the number of customers, their physical location and distances involved, it is not practical to have only one switching centre. Many switching centres are provided, each with its own customers. These centres are interconnected so that customers connected to one exchange have access to customers connected to any other exchange. This is shown in Fig. 1.

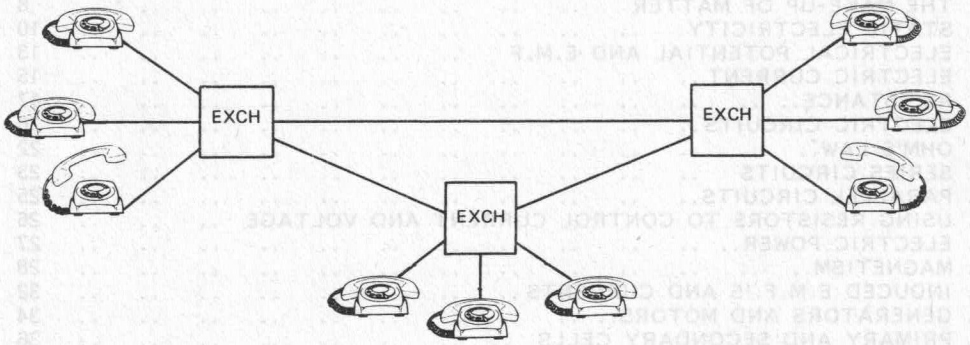


FIG. 1. INTERCONNECTION OF EXCHANGES.

Switching centres in close proximity to each other are grouped together to form a charging zone. Calls to that zone and to adjoining zones, are classed as local calls for which a basic or unit fee is charged. Calls to customers connected to more distant centres are classed as trunk calls, the charge for which is based on the calling distance and the duration of the call. Information regarding the charging zones within a particular area is given in the local telephone directory for that area.

Generally, connections between exchanges within a particular zone and to exchanges in adjoining zones are termed junction circuits, whilst connections to more distant centres are termed trunk circuits.

1.4 SWITCHING SYSTEMS. The connection of calls between customers is usually made by means of automatic exchange switching systems.

In an automatic system, the exchange switching mechanism is controlled by signals transmitted by the dial of the calling customers telephone. The signals are in the form of pulses, and the exchange equipment responds in accordance with the number of pulses received. When the customers replace their handsets, the switching equipment automatically disconnects the call and returns to its unoperated condition. Customer's meters record the number of completed local calls orignated by each customer. Typical automatic exchange equipment is shown in Fig. 2.

1.5 Trunk calls can be connected manually, by means of trunk assistance operators, or automatically. Trunk calls to most centres can be dialled direct by the calling customer; the facility is not yet available in all areas. The facility for direct dialling of trunk calls is referred to as Subscriber Trunk Dialling, or S.T.D. An S.T.D. call is automatically recorded on the calling customer's meter, the distance of the call and its duration being related to the number of meter operations.

Manual Assistance Centres are associated with selected trunk switching centres throughout Australia, and one of their functions is the connection of trunk calls which cannot be dialled directly by the customer.

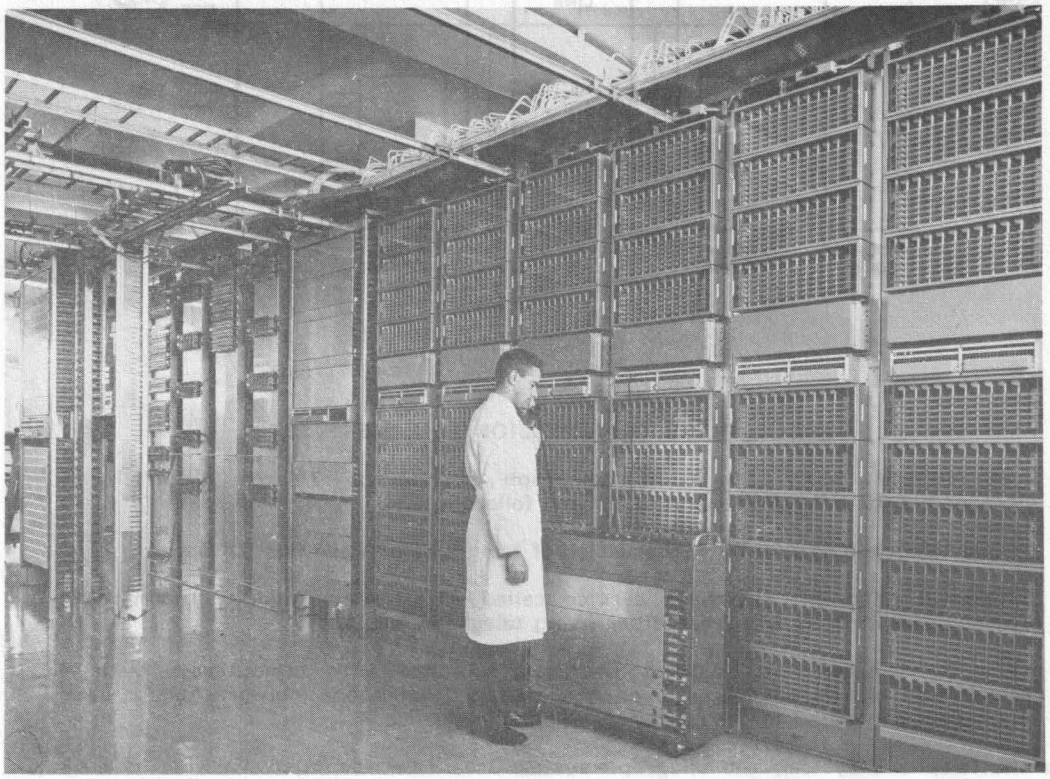


FIG. 2. TYPICAL AUTOMATIC EXCHANGE EQUIPMENT

1.6 METHODS OF TRANSMISSION. In Australia the population is spread over a large area, and the localities served by the telephone system vary from closely settled city areas to sparsely populated rural areas. Each customer's service normally consists of an independent pair of wires between the customer's premises and the exchange. In addition provision must be made for the numerous junction and trunk lines associated with the telephone system.

The method of line distribution for customers, junction and trunk lines varies according to the locality and its amenities. Underground cables are most commonly used in closely settled areas, with open wire lines used in sparsely populated areas; distribution is sometimes by a combination of the two methods. Increasing use is being made of underground cables for important trunk routes, and point to point radio links are often used in place of physical wire lines to provide circuits between switching centres.

1.7 Due to the high cost of providing cables and open wire lines, electronic equipment known as carrier systems are used to enable the simultaneous operation of several telephone or telegraph circuits over one pair of conductors, or a radio link. Many types of carrier systems are in use in Australia providing facilities for the simultaneous operation of from 4 to 2700 circuits over one or two pairs of conductors. Carrier equipment is placed between the exchange switching equipment and the lines as shown in Fig. 3. The subject of the transmission of intelligence over lines is referred to as line transmission.

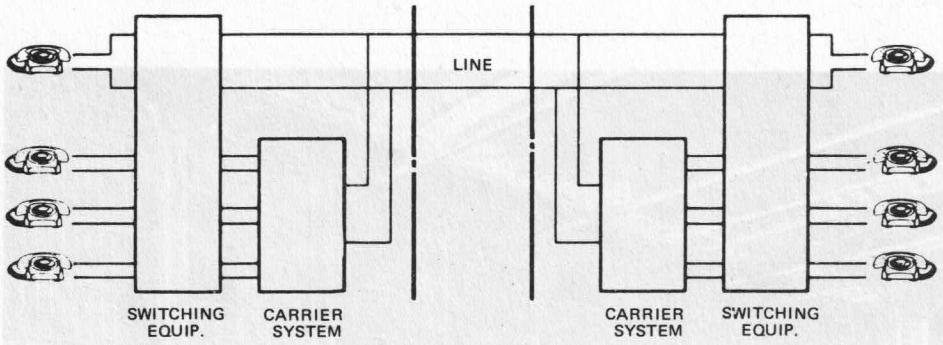


FIG. 3. LINE TRANSMISSION EQUIPMENT.

1.8 TELEGRAPH SERVICES. The telegraph section of Telecom Australia is responsible for providing facilities for the following:

:: Public telegraph system for transmission of telegrams between Post Offices.

:: Automatic telegraph switching service called Telex which allows customers to communicate directly with each other using telegraph machines.

:: Data transmission for business premises equipped with computers. Data is transmitted between centres over the switched telephone network using Datel equipment connected to the customers telephone service.

Like the telephone system, the telegraph system uses Telecoms Australia wide network of switching centres, with access to overseas countries being via the Overseas Telecommunications Commission's Network. Telephone and telegraph systems have separate switching centres but only one network of cables, open wire lines, and carrier systems is provided to meet the requirements of both systems.

1.9 RADIO AND TELEVISION SERVICES. Telecom Australia makes extensive use of radio services, but probably the best known application is in the National Radio and Television Service which is provided by the Australian Broadcasting Commission and Telecom Australia working in close co-operation.

The national radio service is provided throughout Australia by a network of approximately 70 metropolitan and country (regional) transmitting stations, with special transmitting stations providing a service for listeners in remote areas of the Commonwealth, and overseas countries. Radio Australia is part of the latter service. The national television service is provided by approximately 120 transmitting stations which cover the more populous areas, but further transmitting stations are planned which will extend this service to more remote areas.

The television and radio studios are provided and staffed by the A.B.C., which is also responsible for the production and arrangement of all programmes. The majority of programmes originate at studios located in the capital cities, with regional studios providing some segments of programme containing news and items of local interest. Programmes are relayed from the studios to metropolitan and regional transmitting stations over special lines which are provided by, and are the responsibility of Telecom Australia. Telecom is also responsible for providing and maintaining the national radio and television transmitting stations.

2. UNITS AND MEASUREMENTS.

2.1 THE SI SYSTEM. In 1960 the General Conference of Weights and Measures adopted the following six units and quantities as the basis of a practical system of measurement.

Quantity	Unit	Symbol
length	metre	m
mass	kilogramme	kg
time	second	s
electric current	ampere	A
temperature	degree Kelvin	°K
luminous intensity	candela	cd

TABLE 1. BASIC UNITS OF SI SYSTEMS.

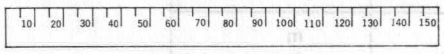
Units defined in terms of these basic units are termed International Units (abbreviated to SI units from the French "Systeme Internationale").

2.2 METRIC MULTIPLES AND SUB-MULTIPLES. In some instances, the standard unit may be either too large or too small for practical common applications. Multiples and submultiples of metric units are formed by using the prefixes shown in Table 2. The prefixes deca and hecto are now very seldom used.

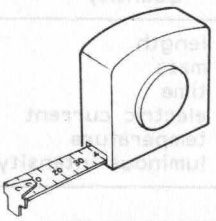
Factor by which Unit is Multiplied	Prefix	Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deca	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
.000 001 = 10^{-6}	micro	μ
.000 000 001 = 10^{-9}	nano	n
.000 000 000 001 = 10^{-12}	pica	p

TABLE 2. METRIC MULTIPLES AND SUB-MULTIPLES.

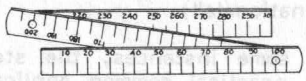
2.3 It would be most unwise to rely on an estimatation of distance or length. One of the most common measurements made by any tradesman is length; the measuring tool or device used depends on the length to be measured. Some of the more common tools used for measuring length include steel or wooden rules, flexible steel and fabric tapes (which are often strengthened with metallic threads). Caution should be exercised when using measuring tools which can conduct electricity, near electrical equipment.



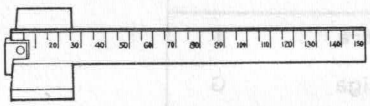
(a) Straight



RETRACTABLE STEEL TAPE.

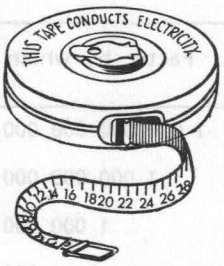


(b) Folding



(c) Hook

TYPICAL STEEL RULES.



FLEXIBLE TAPE.

FIG. 4. LENGTH MEASURING TOOLS.

2.4 Every measurement taken with the tools, shown in Fig. 4, is subject to some degree of error of observation. However if following rules are observed, measurements taken should be reasonably accurate:

:: As the end of the rule may be worn, start your measurement from a major divisions such as the 1 cm mark. Fig. 5 illustrates a measurement being made, starting from the 1 cm division on the rule. Remember, you must deduct one cm from the final measurement.

:: When measuring flat objects lengthwise, be sure that the rule is parallel with the edge of the work. When measuring width, make sure that the rule is at right angles to the edge (Fig. 5) illustrates.

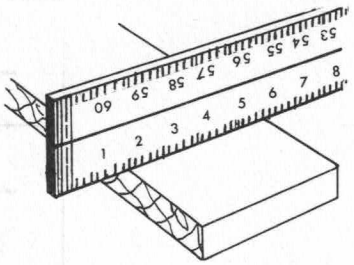


FIG. 5. MAKING ACCURATE MEASUREMENTS WITH A RULE.

:: Place the rule on its edge as shown in Fig. 5 so that the graduated edge is as close as possible to the surface to be measured. Fig. 6 illustrates how "parallax error" can occur if the rule is laid flat and the eye is not exactly above the point of measurement.

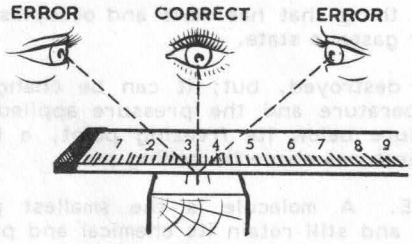


FIG. 6. INCORRECT READINGS RESULTING FROM PARALLAX ERROR.

:: It sometimes happens that the point of measurement does not coincide exactly with any calibration on the rule. In such a case it is necessary to estimate fractions of a division.

2.6 MEASUREMENT OF VOLUME. The volume of a body is the amount of space it occupies. In SI units the volume unit is the cubic metre.

1 litre = 1000 cubic centimetres

1 cubic metre = 100 x 100 x 100 = 1000000 cubic centimetres

The simplest way to measure the volume of a liquid is to pour it into a graduated cylinder and read the graduation corresponding to the level of the liquid surface. The curved liquid surface, is called the meniscus. When the meniscus is convex, Fig. 7a, you should read the graduation corresponding to the top of the meniscus; when the meniscus is concave, you should read the graduation corresponding to the bottom of the meniscus (Fig. 7b).

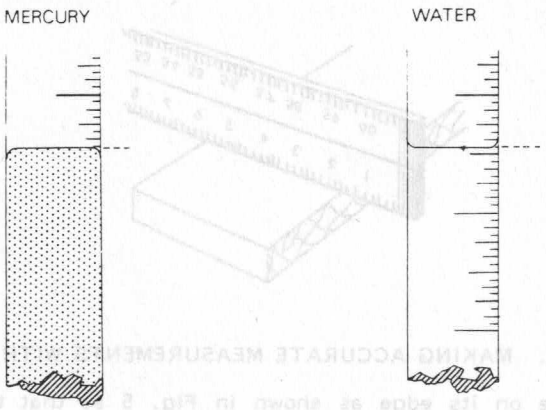


FIG. 7. MEASUREMENT OF LIQUIDS IN A FLASK.

3. THE MAKE-UP OF MATTER.

3.1 Matter is defined as any thing that has mass and occupies space. Matter exists in either a solid, liquid or gaseous state.

Matter cannot be created or destroyed, but; it can be changed from one form to another by changing its temperature and the pressure applied to it. For example, water is a solid at temperature below its freezing point, a liquid at normal room temperature and a gas at temperatures above its boiling point.

3.2 MOLECULAR STRUCTURE. A molecule is the smallest particle into which a substance can be divided and still retain its chemical and physical properties. All matter is made up of molecules, and there are as many types of molecules as there are different substances.

In all matter, the molecules are in a state of rapid and continuous motion. When a solid is heated, the speed of the molecules increases, and they move about more freely. As a result a solid often softens when heated and then melts to a liquid. When a liquid is heated, the molecules move about at an even greater speed, and some may escape in the form of a gas.

The molecule, however, is not the fundamental particle of matter, as most molecules can be further subdivided into smaller particles called atoms.

An atom is the smallest particle of matter that can enter into a chemical combination.

In most cases however, the molecule contains two or more atoms which may be similar, or of different types, depending upon the substance. On this basis, substances can be divided into two groups. These are:

:: ELEMENTS, in which the molecules are composed of atoms of the same type.

:: COMPOUNDS, in which the molecules are combinations of different types of atoms.

FIG. 8 shows how two molecules of the element hydrogen (H_2) combine with one molecule of the element oxygen (O_2), to form two molecules of the compound substance, water (H_2O).

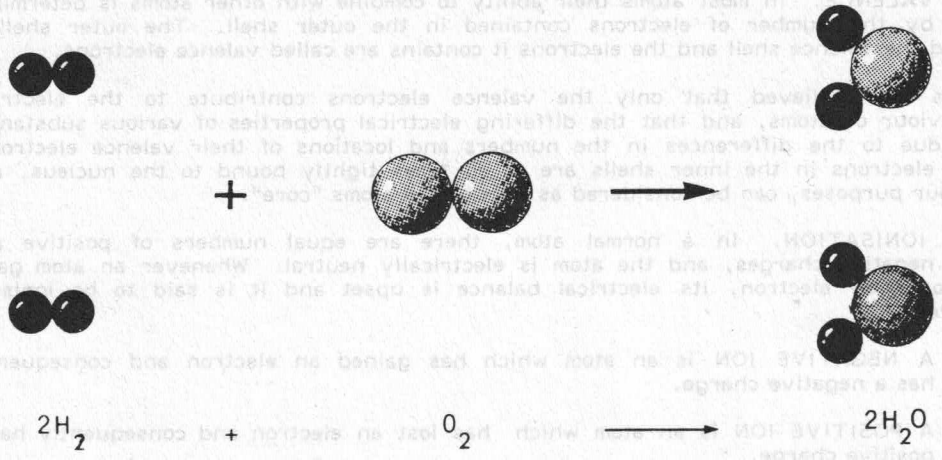


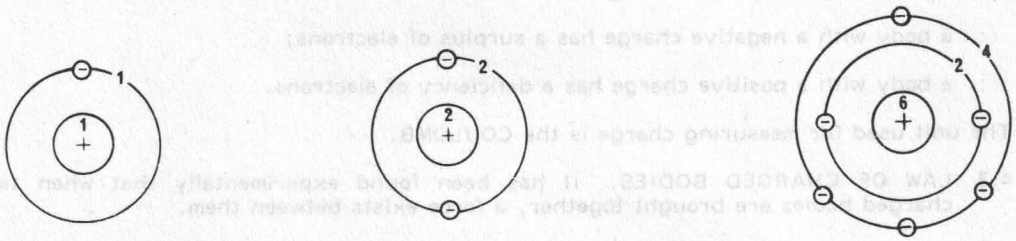
FIG. 8. ELEMENTS COMBINE TO FORM COMPOUNDS.

3.3 ATOMIC STRUCTURE. In all atoms, there is a central nucleus, containing most of the mass of the atom. It is accepted that the nucleus contains particles called protons and neutrons. The nucleus as a whole exhibits a positive electric charge, due to the combined effects of the individual positive charges of the protons. The neutron is uncharged, and as it does not seem to contribute to the electrical behaviour of the atom, we shall not consider it further.

Surrounding the nucleus is a cloud of negative charge, thought to be due to orbiting electrons. Each electron has a charge of the same strength but of the opposite type to that of a proton. All normal atoms have equal numbers of protons and electrons, and therefore an atom as a whole is electrically neutral.

The structure of the simplest atom, that of the element hydrogen, is shown in Fig. 9a. The nucleus contains one proton, and a single electron is shown in orbit around it. An attraction exists between the positively charged nucleus and the negatively charged electron. These forces exactly balance to hold the electron in a stable path in space. The electron's path is called an orbit.

Also represented in Fig. 9b is the helium atom, which has two protons, two neutrons and two electrons, and the carbon atom (Fig. 9c) with six protons, six neutrons, and six electrons. There are more than one hundred different elements, and consequently, more than one hundred atom structures.



(a) Hydrogen Atom (b) Helium Atom (c) Carbon Atom

FIG. 9. SIMPLIFIED ATOMIC STRUCTURES.

3.4 ENERGY LEVELS. An orbiting electron possesses a certain amount of energy. The total energy of an electron determines the shape of its orbit, and for an electron to remain in a particular orbit, it can neither gain nor lose energy.

3.5 VALENCE. In most atoms their ability to combine with other atoms is determined by the number of electrons contained in the outer shell. The outer shell is called the valence shell and the electrons it contains are called valence electrons.

It is now believed that only the valence electrons contribute to the electrical behaviour of atoms, and that the differing electrical properties of various substances are due to the differences in the numbers and locations of their valence electrons. The electrons in the inner shells are at all times tightly bound to the nucleus, and for our purposes, can be considered as part of the atoms "core".

3.6 IONISATION. In a normal atom, there are equal numbers of positive and negative charges, and the atom is electrically neutral. Whenever an atom gains or loses an electron, its electrical balance is upset and it is said to be ionised. Therefore:

:: A NEGATIVE ION is an atom which has gained an electron and consequently has a negative charge.

:: A POSITIVE ION is an atom which has lost an electron and consequently has a positive charge.

Ionisation can occur in a number of ways, such as by bombarding the atom with high velocity atomic particles, by subjecting it to electric fields, or by exposing it to heat, light or other forms of energy radiation.

4. STATIC ELECTRICITY.

4.1 Electricity was first produced by friction. At about the year 600 B.C., the ancient Greeks found that amber, when rubbed with fur or wool, attracted small particles such as leaves and hair. At about 1600 A.D., other substances such as glass, ebony, sealing-wax, resin and sulphur were found to possess similar properties.

4.2 ELECTRIC CHARGE. In the natural state, all atoms are electrically neutral. We have seen however, that one or more electrons can become free, leaving the atom as a positive ion. Also, an atom can gain an electron to become a negative ion.

If a body were composed entirely of neutral atoms, its net charge would be zero. However, all matter is subjected to various forms of energy radiation, so that all bodies contain a certain number of ionised atoms. When a body has equal numbers of positive and negative ions, it is electrically neutral or uncharged. When a body contains more positive ions than negative ions, it is positively charged, but when the negative ions outnumber the positive ions, the body has a negative charge.

Since ions are actually atoms without their normal number of electrons, it is ultimately the number of electrons possessed by a body in relation to its number of protons, which determines its state of charge. Therefore:

:: a body with a negative charge has a surplus of electrons;

:: a body with a positive charge has a deficiency of electrons.

The unit used for measuring charge is the COULOMB.

4.3 LAW OF CHARGED BODIES. It has been found experimentally that when two charged bodies are brought together, a force exists between them.

When the bodies have similar charges, that is, either both positive or both negative, the force is one of repulsion. When the bodies have opposite charges, that is, one positive and one negative, the bodies attract each other.

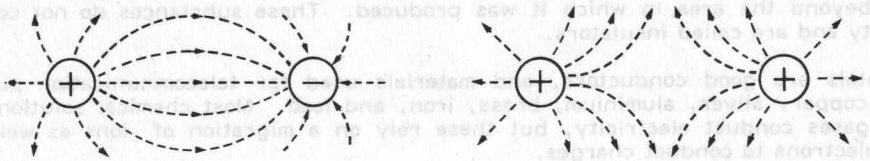
In both cases, the force of attraction or repulsion depends on the strengths of the charges and the distance between them.

This result is summarised in the following law:

:: like charges repel; unlike charges attract.

4.4 ELECTRIC FIELDS. The area surrounding a charged body, where attracting or repelling forces are evident, is known as an electric field. This field exists in a definite pattern, and is often represented by lines radiating in all directions from a charged body. These lines, known as electrostatic lines of force are imaginary, but they help to illustrate the area of influence of charged bodies.

By convention, the lines are shown starting from a positive charge, and ending at a negative charge. The arrows show the direction of the force that would be exerted on a positive test charge if it was placed in the field. Fig. 10a represents the electric field produced by two unlike charges, while that produced by two like charges is shown in Fig. 10b.

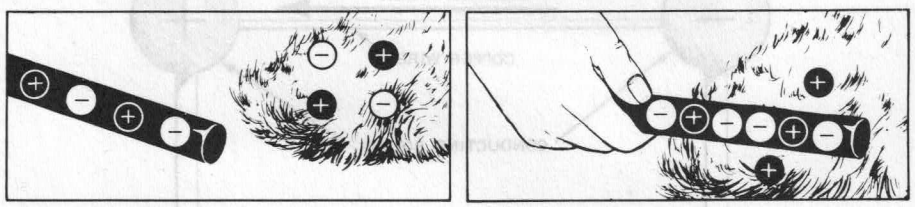


(a) Unlike charges (b) Like charges

FIG. 10. ELECTRIC FIELDS.

4.5 CHARGING BY FRICTION. When two substances are rubbed together, the energy levels of the electrons in both substances are raised to the point where some electrons could become free of their parent atoms. When the substances are different, their different atomic structures allow electrons in one substance to become free before the electrons in the other do so, and a transfer of electrons occurs between them. When this happens, the substance losing the electrons assumes a positive charge, while the substance gaining the electrons assumes a negative charge. The degree and type of charge produced depends on the substances used.

For example, when an ebonite rod is rubbed with fur, the fur loses electrons to the rod. As a result, the rod becomes negatively charged and the fur becomes positively charged, as in Fig. 11a. Similarly, when a glass rod is rubbed with a silk cloth, the glass loses electrons to the silk so that the silk acquires a negative charge while the glass receives a positive charge (Fig. 11b.).



(a) Ebonite and fur.

(b) Glass and silk.

FIG. 11. PRODUCING STATIC CHARGES BY FRICTION.

4.6 CHARGING BY CONTACT. A charged body can transfer some of its charge to other bodies by coming into contact with these bodies.

For example, when a negatively charged ebonite rod is brought into contact with a neutral body, some of the excess electrons on the rod are transferred to the body, leaving it with a negative charge. In the same way, a body can be charged positively by contact with a positively charged glass rod. In this case the rod has a deficiency of electrons, and it attracts some of the electrons from the body, leaving the latter with a positive charge.

4.7 CONDUCTORS AND INSULATORS. When a metallic substance such as copper, brass or aluminium is charged, the charge spreads uniformly over its surface. Electrons can move readily through these materials, and they are called electrical conductors.

When most non-metallic substances are charged, the charge is localised, and does not spread beyond the area in which it was produced. These substances do not conduct electricity and are called insulators.

Most metals are good conductors, and materials used for telecommunication purpose include copper, silver, aluminium, brass, iron, and lead. Most chemical solutions and ionised gases conduct electricity, but these rely on a migration of ions as well as a flow of electrons to conduct charges.

Materials most commonly used as insulators in communication equipment are the plastics, polyvinyl chloride (P.V.C.) and polystyrene. Other substances used as insulators include glass, paper, rubber, ebonite, cotton, silk and porcelain.

4.8 ELECTRON FLOW BETWEEN CHARGED CONDUCTORS. When two oppositely charged conducting bodies are brought into contact, the excess electrons on the negatively charged body are transferred to the other body, where they neutralise its positive charge. The same effect can be achieved by connecting a conductor, such as a piece of copper wire, between the two oppositely charged bodies, as shown in Fig. 12.

The negatively charged body repels electrons in the copper wire, while, at the other end of the wire, the positively charged body attracts them. Electrons therefore, move along the wire towards the positively charged body where they neutralise its charge. These electrons are replaced by an equal number of electrons which enter the wire from the negatively charged body. The result is a general movement of electrons along the conductor, from the negatively charged body to the body with the positive charge.

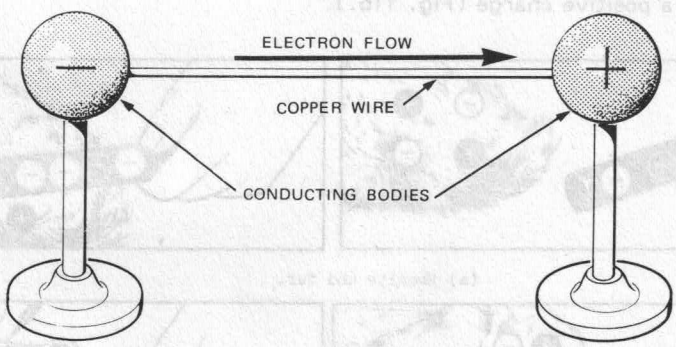


FIG. 12. ELECTRON FLOW IN A CONDUCTOR.

This flow of electrons in the wire will continue until the charges on the bodies are neutralised. If the charges on the bodies are static, for example produced by friction, the flow of electrons will be momentary only.

If, however, the bodies are connected to some device which continually supplies electrons to the negatively charged body and removes electrons from the body with the positive charge, the flow of electrons will be maintained.

The result is a continuous flow of charges from negative to positive, and constitutes an electric current with electrons as the current carriers.

5. ELECTRICAL POTENTIAL AND E.M.F.

5.1 DIFFERENCE OF POTENTIAL. Electric potential is produced whenever substances are electrically charged. For example, when two substances are charged by friction. As the charge is moved from one substance the potential is raised with respect to that of the other, so that a difference of potential exists between them.

It is not necessary for the substances to be oppositely charged to establish a difference of potential. A potential difference exists between two similarly charged substances when the charges are of unequal strength. Fig. 13 illustrates ways in which a potential difference or p.d. can exist between two charged bodies. In all cases , the polarity of the p.d. is the same, that is, A is positive with respect to B.

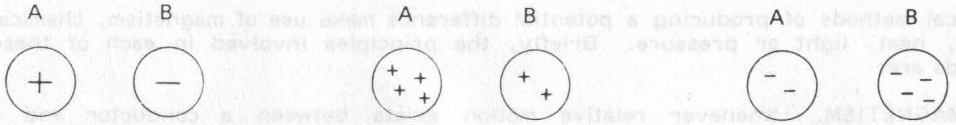


FIG. 13. DIFFERENCE OF POTENTIAL.

Whenever a difference of potential exists between two points, the energy stored in the charge can only be utilised when an electrical conductor is connected between the two points. All electric currents originate from a difference of potential. It is not possible to establish a current between points of equal potential.

5.2 UNIT OF POTENTIAL DIFFERENCE. The unit of potential difference is the VOLT, named in honour of Alessandro Volta, who discovered one of the first practical methods of generating a continuous difference of potential.

The abbreviation for the Volt is V. The potential differences encountered in communications equipment ranges from fractions of a volt to many thousands of volts, so that the more common multiple and submultiple units are:

:: kilovolt (abbreviated kV), $1kV = 1V \times 10^{3}$

:: millivolt (abbreviated mV), $1mV = 1V \times 10^{-3}$

:: microvolt (abbreviated μV), $1uV = 1V \times 10^{-6}$

5.3 ELECTROMOTIVE FORCE. For a potential of difference to become a practical source of voltage, it is essential that the accumulation of charge is maintained, even though the source is supplying current to some external device. A practical voltage source requires an internal action which continually removes electrons from the positive terminal and simultaneously supplies them to the negative terminal.

The force which maintains the state of charge within a source of voltage, and thereby causes the movement of electrons in an electric circuit is called the Electromotive Force.

The abbreviation for Electomotive Force is e.m.f.; the symbol for e.m.f. is E. Like potential difference, e.m.f. is measured in volts.

5.4 DIFFERENCE BETWEEN P.D. AND E.M.F. Although the same basic unit is used to measure p.d. and e.m.f., the terms are not completely interchangeable.

Potential difference is the term used to compare the electrical potential existing between two points. A p.d. exists wherever a voltage can be detected.

On the other hand, electromotive force refers to the rate at which energy is exchanged within a voltage source. In some cases this can be quite different from the p.d. available at its terminals. For example, when a current is drawn from a practical source of voltage, internal losses usually reduce the p.d. measured at its terminals to a value less than the e.m.f.

Therefore, the term "e.m.f." is not a direct alternative for "p.d." or "voltage," and it should only be used when referring to:

:: the force within a device which generates a p.d. at its terminals;

:: the p.d. between the terminals of a source of voltage when it is not delivering current.

5.5 SOURCES OF VOLTAGE. A practical source of voltage is a device which is capable of establishing and maintaining a difference of potential, while some type of electrical apparatus is connected across its terminals. All practical methods of producing a potential of difference rely on the conversion of some form of energy to electrical potential, which can then be converted into work when the source delivers current.

Practical methods of producing a potential difference make use of magnetism, chemical action, heat, light or pressure. Briefly, the principles involved in each of these methods are:

:: MAGNETISM. Whenever relative motion exists between a conductor and a magnetic field, an e.m.f. is generated within the conductor. This principle is used in electric generators, which provide a convenient means of moving conductors in a magnetic field. The principle has important applications in communications equipment.

:: CHEMICAL ACTION. An e.m.f. is produced when two dissimilar conductors are immersed in a chemical solution called an electrolyte. This arrangement constitutes a simple electric cell, and is a means of converting chemical energy into electrical energy. The many types of cells and batteries used to energise communications equipment are applications of this principle.

:: HEAT. A small p.d. is produced when the junction of two dissimilar metals is heated. The value of the p.d. depends upon the metals used and the difference in temperature between the heated and nonheated junctions. This principle is called the "thermoelectric effect", and devices using it are called thermo-couples. Thermo-couples are not widely used for producing large amounts of electrical energy, but they are used in some electrical measuring instruments and as small power supplies.

:: LIGHT. When light falls on certain materials such as selenium, sufficient energy can be transferred to the material to permit electrons to be emitted. This leaves the material with a positive charge, while the surface which collects the electrons acquires a negative charge. This effect is called the "photo-electric effect", and is used in devices called photo-electric cells. The principle is also used in solar cells, which convert solar energy into electrical energy.

:: PRESSURE. If a crystal of quartz is compressed, charges of opposite polarity appear on opposite faces of the crystal. If the force is reversed so that the crystal is stretched, the polarity of the charge reverses. This effect, known as the "piezo-electric effect", is used in certain types of microphones, and in the crystal pick-ups associated with some record players.

A difference of potential can also be produced by friction, but due to the nature of the materials used, and the difficulty of maintaining the charge, this method has limited practical application.

5.6 TYPES OF VOLTAGES. With some methods of producing a potential difference the process is continuous and the polarity of the voltage does not change. With other methods, a voltage is produced only when a change is taking place, and its polarity reverses each time the direction of the change reverses.

Voltages can therefore be classified in two ways:-

:: DIRECT VOLTAGES, where the polarity of the difference of potential does not change. This type of voltage is produced by chemical action, light and heat, and by special electromagnetic generators.

:: ALTERNATING VOLTAGES, where the polarity reverses, usually in a periodic manner. These voltages are commonly derived by electromagnetic means, and from applications of the piezo-electric effect.

5.7 VOLTAGE RATING OF ELECTRICAL EQUIPMENT. Many items of electrical apparatus are designed to operate with a certain applied voltage. If this value is exceeded, damage may result. However; if the voltage is less than the designed value, the current may be insufficient for the correct operation of the equipment.

The voltage required for the correct operation of electrical apparatus is termed it's voltage rating. This value is usually marked on the apparatus, and should not be exceeded.

6. ELECTRIC CURRENT.

6.1 ELECTRIC CURRENT is an ordered movement of charges under the influence of some external force. The symbol for electric current is I.

6.2 UNIT OF ELECTRIC CURRENT. The basic unit used to measure electric current is the AMPERE. The abbreviation for ampere is A. As currents in excess of 1000A are comparatively rare, the ampere is satisfactory as a major unit. In communication equipment, currents of less than one ampere are very commonly encountered and two sub-multiple units are used. They are:

:: milliampere (abbreviated mA), $1mA = 1A \times 10^{-3}$

:: microampere (abbreviated μA), $1\mu A = 1A \times 10^{-6}$

6.3 EFFECTS OF ELECTRIC CURRENT. When an electric current flows in a conductor, it produces effects which can be detected externally. The four principal effects of electric current are:

:: HEATING EFFECT. An electric current heats the conductor through which it flows. This effect is made use of in items such as electric radiators, stoves and soldering irons, and in electric lamps where the temperature is raised to white heat to give light.

:: CHEMICAL EFFECT. When an electric current flows through a conducting liquid, such as an acid or a metallic salt solution, the fluid undergoes a chemical change. This effect is called 'electrolysis', and has application in the action of some types of electric cells, and electroplating.

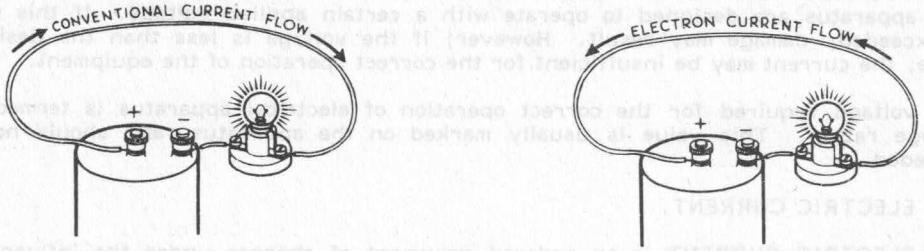
:: MAGNETIC EFFECT. An electric current sets up a magnetic field about the conductor through which it flows. This effect is used in electric bells, telephone receivers, loudspeakers and in almost all electric machinery.

:: PHYSIOLOGICAL EFFECT. An electric current causes muscles to contract when it passes through the human body. In certain instances, this effect can cause death. Provided that normal safety precautions are observed however, there is little danger when working with electricity.

These effects are treated in greater detail in other publications.

6.4 DIRECTION OF CURRENT. It has been shown in previous sections of this paper that current in a conductor is due to the movement of electrons. However, for many years it was assumed that the current was due to a movement of positive charges, and the direction of flow was from positive to negative. This assumption was used to develop many rules to assist in understanding electrical effects.

Conventional current flow as it is now known will form the basis for future Technical Training Publications. However, some publications, including Technical Training Publications, use rules based on electron flow. These rules are, naturally, opposite in a sense to those based on conventional current. It is important to realise that either method of expressing current flow and the associated rules may be used, but, irrespective of what direction of current flow is considered, the results remain unaltered. For example, the globes in Fig. 14 will light for both assumed directions of current flow.



(a) Positive to Negative (b) Negative to positive

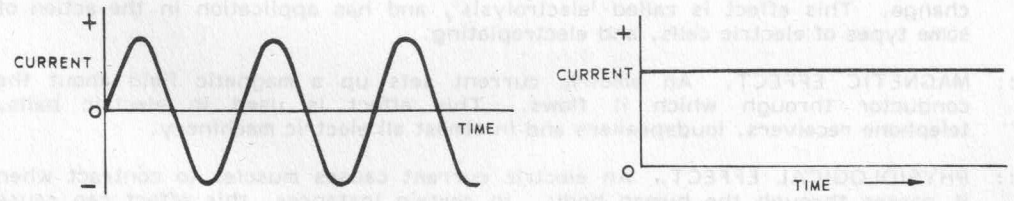
FIG. 14. RESULTS ARE INDEPENDENT OF ASSUMED DIRECTION.

6.5 CLASSIFICATION OF ELECTRIC CURRENTS. Although electric currents can originate from a number of different sources, all electric currents in conductors are similar, in that they consist of flowing electrons. However, the rate of flow is not the same in all cases and even in the same conductor current can vary in value from instant to instant. In addition, the direction of flow can reverse, if the polarity of the applied voltage reverses.

Electric currents are classified into two types:

:: ALTERNATING CURRENT or a.c. regularly alters its direction of flow, first flowing in one direction, then reversing and flowing in the opposite direction as shown graphically in Fig. 15a;

:: DIRECT CURRENT or d.c., flows in one direction only, as shown in Fig. 15b.



(a) Alternating Current (b) Direct Current

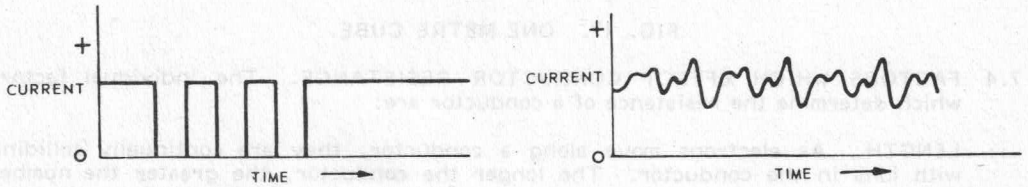
FIG. 15. TYPES OF CURRENT.

Alternating current is used in all branches of electrical engineering. For example, the commercial power supply provides A.C. for lighting and power. In communications, alternating currents are used for purposes ranging from television transmission to ringing telephone bells. Although many alternating currents have a waveform which corresponds with the "sine-wave" shown in Fig. 15a, this is not an essential characteristic of a.c., and in many communication applications, non sine-waves are used.

Direct Current shown in Fig. 15b maintains a constant value, and is sometimes called a steady direct current. In communications, this type of current is comparatively rare, as in most cases the currents are constantly changing in value. There are two types of direct currents. These are:

:: PULSATING CURRENT, which is a form of d.c. which flows in pulses, having complete periods of no current, as shown in Fig. 16a.

:: VARYING CURRENT, which is also unidirectional, and varies in value from instant to instant as shown in Fig. 16b.



16 (a) Pulsating Current 16 (b) Varying Current

FIG. 16. FLUCTUATING CURRENTS.

Pulsing currents are commonly used in telegraph working. The current shown in Fig. 16a is a graphical representation of the current sent to line from a modern telegraph machine when a key is depressed. Pulsating current is usually derived by periodically interrupting steady direct current.

Varying currents are often employed in telephone working. For example, the process of the electrical transmission of speech starts with a varying current similar to that shown in Fig. 16b, flowing in a telephone transmitter. Varying currents are sometimes derived from varying direct voltages, but more often, they are the result of applying steady direct voltages to items of equipment which offer varying amounts of opposition to current.

7. RESISTANCE.

7.1 Different substances allow the passage of electric current, but not all substances conduct to the same degree. Some conductors offer very little opposition to current flow; others oppose it to a great extent.

The amount of opposition offered by a body to the flow of electric current is called its resistance. The symbol used to indicate resistance is R.

7.2 UNIT OF RESISTANCE. The unit of resistance is the OHM. A conductor has a resistance of one ohm when a p.d. of one volt applied across its ends causes a current of one ampere.

The abbreviation for ohm is the Greek Letter Ω (omega). Other multiple and submultiple units in common use are:

:: the megohm (abbreviation MΩ), $1M\Omega = 1\Omega \times 10^6$

:: the kilohm (abbreviated kΩ), $1k\Omega = 1\Omega \times 10^3$

:: the microhm (abbreviated μΩ), $1\mu\Omega = 1\Omega \times 10^{-6}$.

7.3 RESISTIVITY. One of the factors which determines the resistance of a body is the material from which it is made. The degree of opposition the material offers to the passage of an electric current is determined by the material's atomic structure. This opposition is a characteristic of the material, and is called resistivity.

The resistivity of a material is the resistance measured between opposite faces of a metre cube of the substance (Fig. 17) at a given temperature.

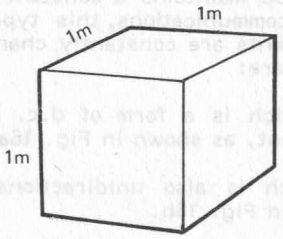


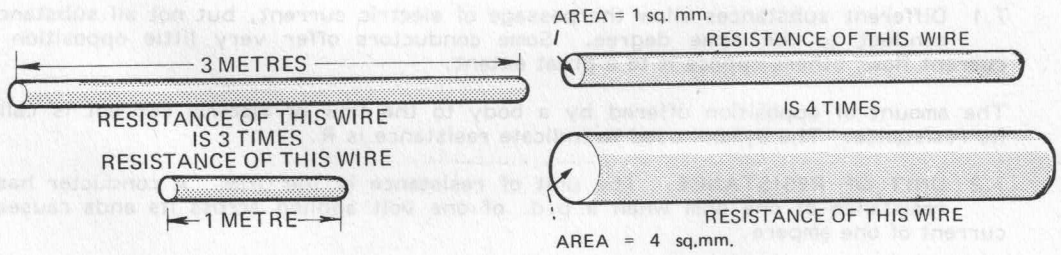
FIG. 17. ONE METRE CUBE.

7.4 FACTORS WHICH EFFECT CONDUCTOR RESISTANCE. The individual factors which determine the resistance of a conductor are:

:: LENGTH. As electrons move along a conductor, they are continually colliding with ions in the conductor. The longer the conductor, the greater the number of collisions, and the greater is the opposition to the current. Provided that all other factors are equal, a conductor twice the length of another has twice its resistance, while a conductor three times the length of another (Fig. 18a) has a resistance three times that of the shorter wire.

:: CROSS-SECTIONAL AREA. For a given type of material, there are more current carriers available in a conductor of large cross-section than there are in a conductor of smaller cross-section. Therefore the conductor with the larger cross sectional area has the lower resistance. When the cross-sectional area of one conductor is double that of another, its resistance is half that of the smaller conductor. Similarly, a conductor with four times the cross-sectional area of another (Fig. 18b), has one quarter of its resistance.

:: RESISTIVITY. The electrical properties of a material are indicated by its resistivity. Provided that the length and cross-sectional area are the same, a conductor made from a material with a high resistivity has more resistance than a conductor made from a material with a low resistivity.



(a) Resistance depends upon length

(b) Resistance depends upon cross-sectional area

FIG. 18. FACTORS AFFECTING CONDUCTOR RESISTANCE.

7.5 RESISTORS. Resistance is inherent in all electrical equipment. In some cases, the effects of this resistance are undesirable, and special techniques are adopted to reduce resistance to a minimum value. In other instances, the natural resistance of a wire or component is insufficient for a particular application, and additional resistance is intentionally added.

Components designed specifically to offer resistance to electric current are called resistors. Many different types of resistors are used in communications equipment. These can be of the fixed value or of the variable resistance type.

7.6 FIXED RESISTORS. Fixed resistors provide a resistance value which cannot be changed. These resistors can be broadly classified according to the materials from which the resistance elements are made. These are:

:: WIRE WOUND RESISTORS usually consist of a suitable length of resistance wire wound on an insulating bobbin or former. This type of resistor is generally used in high current applications, or where extreme accuracy and stability of resistance value is required. They are available in resistance values ranging from a fraction of an ohm up to about 100 kilohms.

:: CARBON RESISTORS are made from carbon or carbon composition rod, or by depositing a thin layer of pure carbon on an insulating tube. These resistors are the most commonly used type, and are available in a range of resistance values from 10 ohms to 22 megohms.

:: METAL OXIDE RESISTORS consist of a thin film of metal oxide on a ceramic rod. Generally, these resistors offer closer tolerances and higher stability than carbon resistors. The range of values available is typically from a few ohms to about 100 kilohms.

Some typical fixed resistors are shown in Fig. 19.

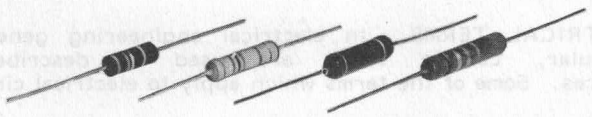


FIG. 19. TYPICAL FIXED RESISTORS.

7.7 VARIABLE RESISTORS. Variable resistors are specially constructed so that their resistance can be varied or adjusted to any value within the range of resistances provided. The resistance element can be wire wound or made from a carbon composition, and the variation in resistance is derived by moving a wiper arm or adjustable clamp along the resistance element.

Variable resistors usually have three terminals or connection points. The two outside terminals connect to the ends of the resistance element, while the middle terminal connects to the wiper arm or its equivalent. Some typical variable resistors are shown in Fig. 20.

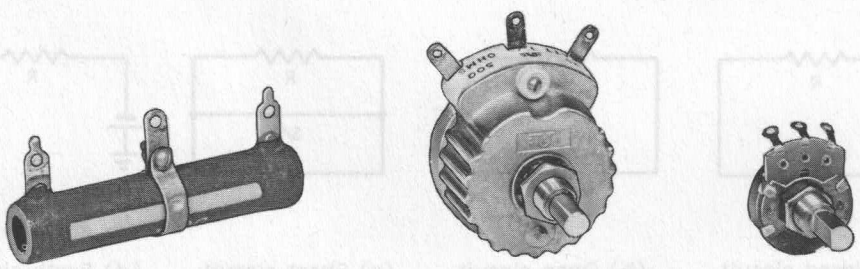


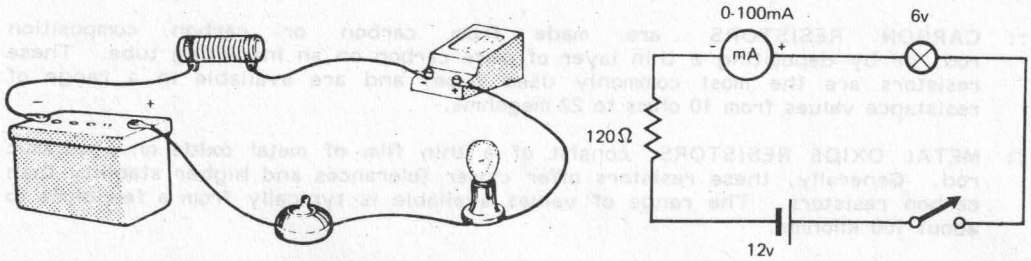
FIG. 20. TYPICAL VARIABLE RESISTORS.

8. ELECTRIC CIRCUITS.

8.1 The term "circuit" refers to the complete path for electric current, including the source of voltage, the connecting wires and the circuit components. Modern communication systems are usually made up from a number of smaller circuits each of which plays its part in the overall operation. A knowledge of the principles of electric circuits is essential to the understanding or operation of communications equipment, as the performance of the system as a whole depends to a large extent on each of the smaller circuits working correctly.

8.2 CIRCUIT DIAGRAMS. Whenever it is necessary to represent an electrical circuit diagramatically, the circuit components are shown by standard symbols joined by lines to represent the connecting wires. These diagrams are called schematic circuit diagrams, or more commonly, schematic circuits.

A simple electrical circuit is shown pictorially in Fig. 21a. A lamp, (rated at 6 volts) is connected to a 12 volt battery via a limiting resistor and a switch. A milliammeter is included to measure the current. The schematic circuit equivalent to this diagram is shown in Fig. 21b.



(a) Pictorial diagram (b) Schematic circuit

FIG. 21. CIRCUIT DIAGRAM.

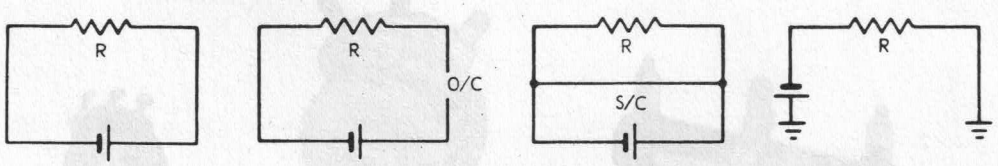
8.3 ELECTRICAL TERMS. In electrical engineering generally, and in Telecom in particular, certain terms are used to describe commonly encountered circumstances. Some of the terms which apply to electrical circuits are:

:: CLOSED CIRCUIT applies when a circuit is complete, and electric current is flowing. (Fig. 22a).

:: OPEN CIRCUIT is the condition of a circuit when the continuity has been broken (Fig. 22b) and current ceases to flow.

:: SHORT CIRCUIT describes the situation when a part or the whole of the circuit is shunted by a low resistance path (Fig. 22c) and current does not flow in the correct circuit.

:: EARTH CIRCUIT applies when the earth forms part of the circuit as in Fig. 22d.



(a) Closed circuit (b) Open circuit (c) Short circuit (d) Earth circuit

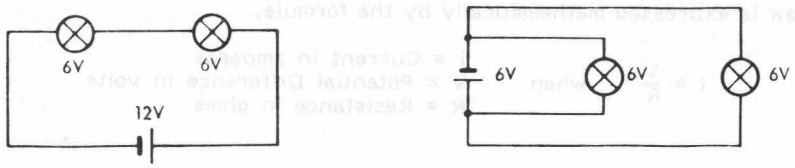
FIG. 22. ELECTRICAL TERMS

8.4 TYPES OF CIRCUITS. In most cases, communications equipment consists of large numbers of smaller components connected together in such a way as to perform the desired function. Although the circuit diagram of major equipment items are often extremely complex, in most cases these can be broken down into smaller units in which the circuit connections are quite basic.

There are two basic types of electric circuits. These are:

:: SERIES CIRCUITS, where the current flows in a single continuous path through each component. If the circuit is broken at any point, current ceases to flow in the entire circuit. A simple series circuit containing two 6 volt lamps operating from a battery is shown in Fig. 23a.

:: PARALLEL CIRCUITS, in which the current divides and flows in two or more branch circuits. In a parallel circuit, a break in the continuity only affects the branch in which the break occurs. Fig. 23b shows two 6 volt lamps operating in parallel.



(a) Series circuit (b) Parallel circuit

FIG. 23. BASIC ELECTRIC CIRCUITS.

Examples of series and parallel circuits are to be found in the electrical apparatus used in our homes. For example, the coloured lights used to decorate home Christmas trees are an example of a series circuit. The individual lights are connected in series with one another and operated from the electricity supply main. If one lamp fails, the entire chain is extinguished; when the faulty lamp is replaced, the lights come on again.

The electrical wiring in our homes is a practical example of a parallel circuit, as all lights and power outlets are connected in parallel with the electricity supply main. This connection allows individual lights and appliances to be turned on or off without affecting other lights and appliances.

8.5 SERIES-PARALLEL CIRCUITS. It is also possible to derive an electrical circuit which is a combination of the series and parallel types. This type of circuit is part series and part parallel, and is called a series-parallel circuit.

A simple series-parallel circuit is shown in Fig. 24a, which represents a lamp rated at 6 volts, connected in series with two similar 6 volt lamps which are connected in parallel. The combination operates from a 12 volt battery.

Another type of series-parallel connection is shown in Fig. 24b. In the circuit, a 12 volt lamp is connected in parallel with two 6 volt lamps which are operating in series. The three lamps operate from a 12 volt battery.

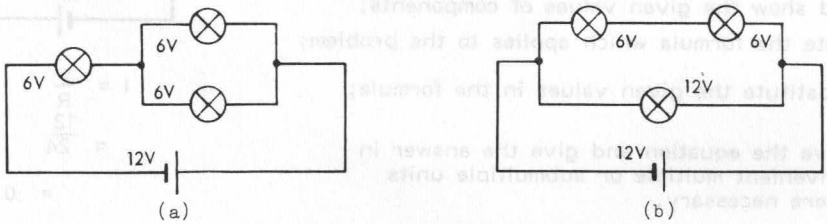


FIG. 24. SERIES-PARALLEL CIRCUITS.

9. OHM'S LAW.

9.1 In the early part of the nineteenth century, Dr. George Simon Ohm, a German physicist, proved by experiment that a precise relationship existed between the current and voltage in an electrical circuit. The statement in which his findings are summarised is called Ohms's Law.

9.2 OHM'S LAW defines the relationship between current, voltage and resistance and is stated as follows:

"The current in an electric circuit is directly proportinal to the applied voltage, and inversely proportional to the circuit resistance."

Ohm's Law is summarised by these statements:

:: increasing the applied voltage causes a corresponding increase in current;

:: increasing the resistance causes a corresponding decrease in current.

Ohm's Law is expressed mathematically by the formula,

$$I = \frac{V}{R}$$ when I = Current in amperes, V = Potential Difference in volts, R = Resistance in ohms

When any two quantities are known, the formula can be transposed to find the third. Therefore:

$$R = \frac{V}{I} \quad \text{and} \quad V = I \times R$$

9.3 APPLYING OHM'S LAW. Ohm's Law can be used to determine the current, the voltage, or the resistance in an electrical circuit. To find the value of any one of these quantities, it is necessary to know the values of the other two.

When solving electrical circuit problems, it is essential to adopt a systematic approach to the method of calculation. A typical step-by-step approach is outlined in Example No. 1.

When applying Ohm's Law to solve a circuit problem, remember:

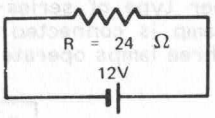
:: all quantities used must be taken from the same relative part of the circuit;

:: the quantities must be expressed in amperes, volts, and ohms.

9.4 USING OHMS LAW TO CALCULATE CURRENT - EXAMPLE 1. Calculate the current when a circuit having a resistance of 24 ohms is connected to a voltage source of 12 volts:

:: read and understand the question;

:: draw a simple schematic circuit for the problem, and show the given values of components;



:: state the formula which applies to the problem;

:: substitute the given values in the formula;

$$I = \frac{V}{R}$$

:: solve the equation and give the answer in convenient multiple or submultiple units where necessary.

$$= \frac{12}{24}$$

$$= 0.5 \text{ Amps}$$

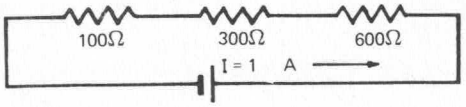
9.5 USING OHM'S LAW TO CALCULATE DROP OF POTENTIAL IN ELECTRIC CIRCUITS. When current flows in a circuit component which contains resistance, a difference in potential is produced across it. This p.d. is often called a "drop of potential", and is an indication that work is done in overcoming the opposition offered by the component.

The magnitude of this drop of potential depends upon the value of the resistance and the value of the current. In all cases, the value of the drop of potential can be calculated by applying Ohm's Law.

9.6 EXAMPLE NO. 2. A circuit contains resistors of 100 ohms, 300 ohms and 600 ohms connected in series. If the current in the resistors is 1 Ampere calculate:

(a) the p.d. across the 100 ohm resistor.

(b) the p.d. across the 600 ohm resistor.



(a) $V = I \times R$

$= 1 \times 100$

$= 100$ volts

(b) $V = I \times R$

$= 1 \times 600$

$= 600$ volts

Answers (a) 100 volts (b) 600 volts

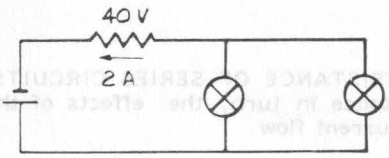
9.7 USING OHM'S LAW TO CALCULATE RESISTANCE. Ohm's Law can be used to find the resistance of a circuit, or part of a circuit, when the current and voltage in the particular part of the circuit are known.

9.8 EXAMPLE NO. 3. A resistor is connected in series with two parallel-connected lamps and a battery. If the current through the resistor is 2A, and the p.d. across it is 40 volts, find the resistance of the resistor.

$$R = \frac{V}{I}$$

$$= \frac{40}{2}$$

$= 20$ Ohms.



10. SERIES CIRCUITS.

10.1 In series circuits, the current has only one path, and the same value of current flows in each component. When current flows in the circuit, a potential drop is produced across each part of the circuit which contains resistance.

Fig. 25 shows three resistances R1, R2 and R3 connected in series to a voltage source, V. The current I, produces the potential drops, V1, V2 and V3.

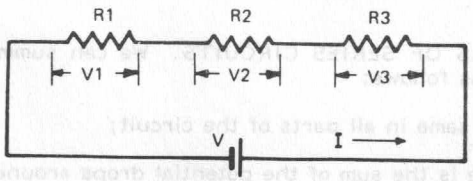


FIG. 25. SERIES CIRCUIT.

10.2 CURRENT IN SERIES CIRCUITS. As there is only one path for current, the current in R1 is the same as that in R2 and R3. In a series circuit therefore, the current is the same in all parts.

10.3 VOLTAGES IN SERIES CIRCUITS. The voltages present in a series circuit are the applied voltage, and the potential drops across the individual resistances in the circuit. Each p.d. represents that part of the potential of the applied voltage which is expended in overcoming the resistance of that part of the circuit.

The sum of the potential drops is equal to the applied voltage.

In Fig. 25 therefore:

$V = V1 + V2 + V3$ where

V = Applied p.d. in volts

V1
V2 = Circuit p.ds in volts
V3

The value of each of the potential drops in the circuit can be found from Ohm's Law.

This is, $V1 = I \times R1$

$V2 = I \times R2$ where

$V3 = I \times R$

V1
V2 = Circuit p.ds in volts
V3

I = Current in amperes

R1
R2 = Circuit resistances in ohms
R3

10.4 TOTAL RESISTANCE OF SERIES CIRCUITS. As the path for current is through each resistance in turn, the effects of the individual resistances are cumulative in limiting the current flow.

In a series circuit therefore, the total resistance is the sum of the individual resistances in the circuit:

In Fig. 25,

$RT = R1 + R2 + R3$ where

RT = Total resistance in ohms

R1
R2 = Circuit resistances in ohms
R3

10.5 CHARACTERISTICS OF SERIES CIRCUITS. We can summarise the characteristics of series circuits as follows:

:: the current is the same in all parts of the circuit;

:: the applied voltage is the sum of the potential drops around the circuit;

:: the total resistance is the sum of the individual resistances in the circuit.

11. PARALLEL CIRCUITS.

11.1 In a parallel circuit, there are as many current paths as there are branch circuits. The current from the source of voltage divides, and part flows in each branch circuit.

Fig. 26 shows three resistances R1, R2 and R3 connected in parallel to a source, V. The total current I, divides into the branch circuits I1, I2, and I3,

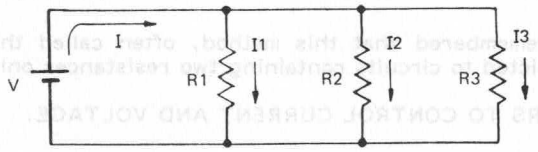


FIG. 26. PARALLEL CIRCUIT.

11.2 VOLTAGE IN PARALLEL CIRCUITS. As all the branch circuits are connected to the same point, the p.d. across R1 is the same as that across R2 and across R3. In a parallel circuit, therefore, the p.d. is the same across each parallel branch.

In simple circuits such as Fig. 26, the p.d. across each branch is also equal to the voltage of the source.

11.3 CURRENTS IN PARALLEL CIRCUITS. The total current divides so that part flows in each of the branch circuits. After passing through the branch circuits, the branch currents recombine to return to the source. Therefore, the sum of the branch currents equals the total current.

In Fig. 26, therefore:

$$I = I_1 + I_2 + I_3$$

when

I = Total current in amperes

I_1
I_2 = Branch currents in amperes
I_3

The value of each of the branch currents can be found from Ohm's Law.

That is,

$$I1 = \frac{V}{R_1} \qquad I = \frac{V}{R} \qquad I2 = \frac{V}{R_2} \qquad I3 = \frac{V}{R_3}$$

where

I_1
I_2 = Branch currents in amperes
I_3

V = Applied p.d. in volts

R_1
R_2 = Branch resistances in ohms
R_3

These rules are summarised as follows:

:: the current flowing into a parallel group of components equals the sum of the individual branch currents in the group;

:: the same voltage exists across each branch of a parallel group.

11.4 TOTAL RESISTANCE OF TWO PARALLEL RESISTANCES. When the circuit contains only two parallel paths, the basic formula for total resistance is:

$$\frac{1}{RT} = \frac{1}{R1} + \frac{1}{R2}$$

or

$$RT = \frac{R1 \times R2}{R1 + R2}$$

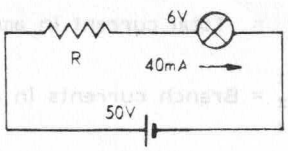
It must always be remembered that this method, often called the "product over the sum" method, is restricted to circuits containing two resistances only.

12. USING RESISTORS TO CONTROL CURRENT AND VOLTAGE.

12.1 To vary the current in a circuit, or to change the p.d. across an item of equipment, either the applied voltage or the resistance must be altered. In practice, altering the resistance is generally the simplest way available, and often additional resistors are included in the circuit for control purposes. These resistors can be of the fixed value or variable type, and they can be connected in series or in parallel with the circuits they control.

12.2 USE OF A FIXED RESISTOR IN SERIES. A resistor can be connected in series with a circuit when it is desired to limit the current to a certain value, or when it is required to reduce the p.d. across one of the circuit components. Often, a resistor is connected in series with a component to allow the component to operate from a circuit voltage source higher than its voltage rating.

Fig. 27 shows an application of this method. It is desired to operate a small switch-board lamp from a 50 volt battery. The lamp is rated at 6 volts and operates normally with a current of 40mA. The series resistor used must therefore produce a p.d. of 44 volts when the current is 40mA.



$$\text{Value of } R = \frac{V}{I}$$

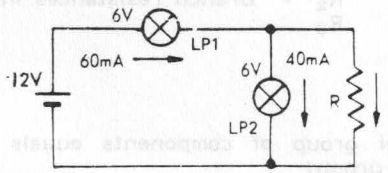
$$= \frac{44}{40} \times \frac{1000}{1}$$

$$= 1100\Omega$$

FIG. 27. USING A SERIES RESISTOR TO CONTROL VOLTAGE.

12.3 USE OF A FIXED RESISTOR IN PARALLEL. There are occasions when it is necessary to connect in series, two items which have different current requirements. In these cases, a resistor can be connected in parallel with the low current item, so that the total current of this combination equals the operating current of the other item of equipment.

Fig. 28 shows how two 6 volts lamps, LP1 and LP2, with operating currents of 60mA and 40mA respectively, are operated from a 12 volt battery. The value of the parallel resistor is chosen so that with a p.d. of 6 volts, its current is equal to the difference between the lamp currents.



Current in R = 20mA

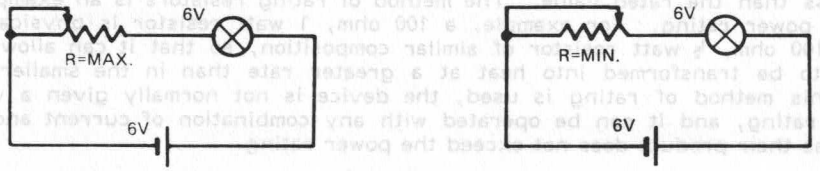
$$\text{Value of } R = \frac{V}{I}$$

$$= \frac{6}{20} \times \frac{1000}{1}$$

FIG. 28. USING A PARALLEL RESISTOR TO CONTROL CURRENT.

12.4 USE OF A VARIABLE RESISTOR. A variable resistor connected in series with a piece of equipment for the purpose of controlling the current is usually called a rheostat.

An example of the use of a rheostat is shown in the simple lamp dimming circuit of Fig. 29. When the rheostat is set for maximum resistance (Fig. 29a) the value of the current is reduced and the lamp is dimmed. When the rheostat is set for minimum resistance, (Fig. 28b) the lamp glows normally.



(a) Lamp dimmed (b) Lamp normal

FIG. 29. USING A RHEOSTAT TO CONTROL CURRENT.

13. ELECTRIC POWER.

13.1 The unit of electric power is the Watt, the abbreviation for which is W. The power in a circuit is one watt when a current of one ampere is produced by an applied voitage of one volt. Also a circuit component transforms energy at the rate of one watt when a current of one ampere produces a potential drop of one volt across its terminals.

This relationship is expressed by the formula:

$P = V \times I$ where P = Power in watts, V = Potential difference in volts, I = Current in amperes

Where large powers are involved, multiple units are used. These are:

:: the kilowatt (abbreviated kW), $1kW = 1W \times 10^3$;

:: the megawatt (abbreviated MW), $1MW = 1W \times 10^6$.

In communications, the power used is often much less than a watt, and submultiple units are used. These are:

:: the milliwatt (abbreviated mW), $1mW = 1W \times 10^{-3}$;

:: the microwatt (abbreviated μW), $1\mu W = 1W \times 10^{-6}$.

13.2 POWER IN SERIES AND PARALLEL CIRCUITS. The power in any component in any type of circuit, that is, series, parallel, or series-parallel, can be determined by application of the appropriate formula. The values used however, must be taken from the particular part of the circuit under consideration.

13.3 POWER RATING OF ELECTRICAL APPARATUS. Most items of electrical apparatus are given a power rating. The power rating in watts indicates the rate at which the device converts electrical energy into energy of another form.

In some cases, the power rating indicates the actual power of the device when it is operated under specified conditions. For example, a 240 volt, 100 watt lamp transforms electrical energy into light and heat at the rate of 100 watts when it is connected to a 240 volt supply.

In other instances, the power rating indicates the maximum power that the device is designed to dissipate. When the device is operating normally, the power may be much less than the rated value. The method of rating resistors is an example of this type of power rating. For example, a 100 ohm, 1 watt resistor is physically larger than a 100 ohm, ½ watt resistor of similar composition, so that it can allow electrical energy to be transformed into heat at a greater rate than in the smaller resistor. Where this method of rating is used, the device is not normally given a voltage or current rating, and it can be operated with any combination of current and voltage, as long as their product does not exceed the power rating.

14. MAGNETISM.

14.1 Magnetic materials are those which attract or repel ferrous metals. The attracting and repelling property of a magnet is called magnetism, and a substance which possesses this property is said to be magnetised.

14.2 MAGNETIC MATERIALS. Materials which can be readily magnetised are called magnetic materials. Magnetism is most noticeable in iron and steel, but often, small amounts of nickel, chromium, cobalt, tungsten and other materials are added to iron to make special alloys which have magnetic properties suitable for different applications.

Other substances, such as brass, copper, aluminium, zinc and glass are practically nonmagnetic. These substances however, allow magnetism to pass without themselves becoming magnetised to any extent.

14.3 MAGNETS. All magnets used in communications equipment are artificially produced and these can be of two kinds. These are:

:: PERMANENT MAGNETS, retain their magnetism indefinitely unless subjected to demagnetising forces such as heat or jarring.

:: TEMPORARY MAGNETS, quickly lose their magnetism when the magnetising force is removed. Temporary magnets derive their magnetism from the magnetic effects of electric current and are called electromagnets.

14.4 MAGNETIC POLES. The force of attraction or repulsion exhibited by a magnet is not uniform, but is concentrated at two points called magnetic poles. The part of the magnet midway between the poles exhibits little or no magnetism and is called the neutral zone. These regions are indicated in Fig. 30 which shows the effect of dipping a bar magnet into a pile of iron filings.

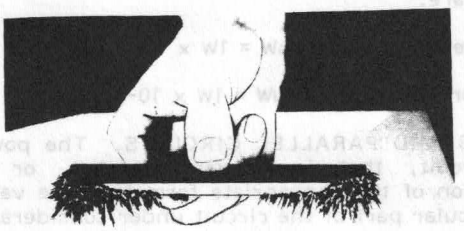


FIG. 30. MAGNETIC POLES.

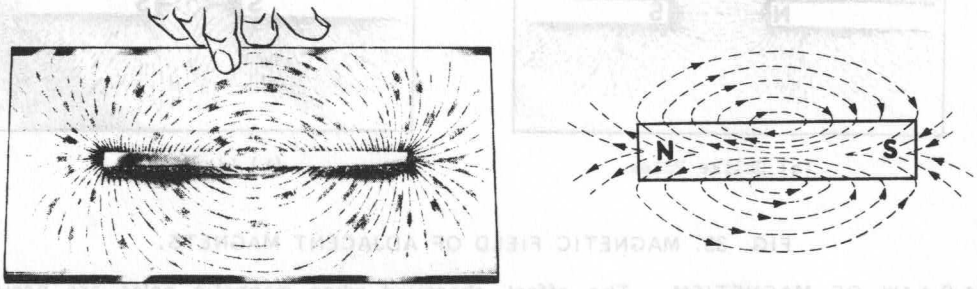
14.5 MAGNETIC FIELDS. Magnetism is an invisible force and can only be seen in terms of the effects it produces. The space in the vicinity of a magnet, in which the forces of attraction and repulsion are apparent, is called a magnetic field.

To assist in the understanding of magnetic effects, magnetic fields are usually represented by lines drawn to show the area of influence of the magnet. These lines are called lines of force.

By convention, it is assumed that the lines of force leave the magnet at the north pole, travel through the surrounding space to re-enter at the south pole. The lines of force then travel inside the magnet from the south pole to the north pole to complete closed loops. Each closed loop tends to be as short as possible, but as loops repel adjacent loops, they never cross.

14.6 FIELD PATTERN FOR A BAR MAGNET. The pattern and arrangement of these lines of force can be traced by moving a compass needle around a magnet, or by sprinkling iron filings on a glass plate or a piece of paper placed on top of the magnet. The filings form a regular pattern when the glass or paper is gently tapped.

The magnetic field pattern obtained in this way is shown in Fig. 31a. The conventional method of representing this field by lines of force is shown in Fig. 31b.



(a) Pattern with Filings. (b) Pattern With Lines of Force.

FIG. 31. MAGNETIC FIELD OF BAR MAGNET.

14.7 FIELD PATTERN FOR A HORSESHOE MAGNET. A horsehoe magnet is essentially a bar magnet which has been formed into a horseshoe shape so that the poles are adjacent. This shape concentrates the field inside the horseshoe at the end of the magnet as shown by Fig. 32a.

The magnetic field pattern for a horseshoe magnet is represented by lines of force in the conventional manner as shown in Fig. 32b.

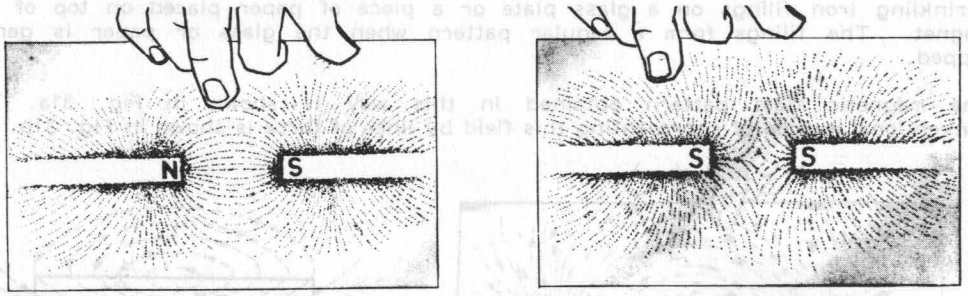
(a) Pattern with filings (b) Pattern with lines of force

FIG. 32. MAGNETIC FIELD OF HORSESHOE MAGNET.

14.8 ATTRACTION AND REPULSION OF MAGNETIC POLES. By observing the reactions of a compass needle when it is placed near a bar magnet, the north pole of the needle is attracted to the magnet's south pole and repelled by the magnet's north pole. The south pole of the needle is always attracted to the north pole of the magnet, but repelled by the south pole.

This attraction or repulsion between the poles is due to the aiding or opposing of the lines of force of the magnets. For example, when two bar magnets are placed end to end, and iron filings are used to map out the lines of force, the effects are shown in Fig. 33.

With unlike poles (Fig. 33a), the lines of force from each magnet link up and draw the poles together so that the magnets attract one another. With like poles (Fig. 33b), the lines of force are crowded and tend to push the poles apart, so that the magnets repel.



(a) Unlike Poles. (b) Like Poles.

FIG. 33. MAGNETIC FIELD OF ADJACENT MAGNETS.

14.9 LAW OF MAGNETISM. The effect observed when magnetic poles are brought near to one another is known as the Law of Magnetism.

This Law states:

:: Like poles repel and unlike poles attract.

14.10 MAGNETIC INDUCTION. When a magnet is brought near to unmagnetised material (such as iron) the iron is attracted to it. Since attraction only occurs between unlike magnetic poles, it is reasonable to assume that the iron becomes magnetised. This process is called magnetic induction.

14.11 RESIDUAL MAGNETISM. When magnetic material has been magnetised by induction, it usually retains some of the induced magnetism after the magnet has been removed. The magnetism that remains after the magnetising force has been withdrawn is called the residual magnetism.

14.12 MAGNETIC SCREENING. In communications equipment, it is often necessary to prevent magnetic fields from effecting nearby components. This is achieved by placing a screen around either the source of the interfering magnetic field or the components to be protected.

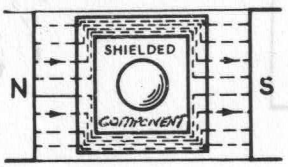


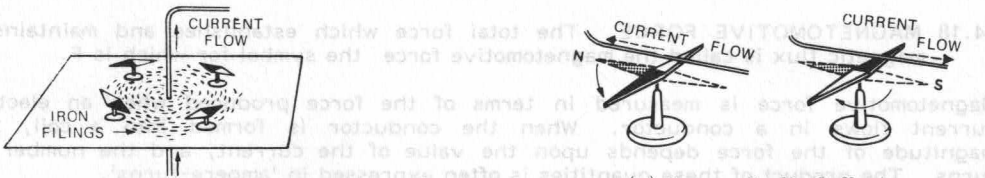
FIG. 34. MAGNETIC SCREENING.

The principle of magnetic screening is illustrated in Fig. 34. Components requiring screening are enclosed in an iron can or case. Most of the lines of force then travel through the iron which provides an easier path than air. The effectiveness of the screen depends upon the thickness of the case and the magnetic characteristics of the iron from which it is made.

14.13 MAGNETIC FIELD ABOUT A CURRENT-CARRYING CONDUCTOR. By a number of simple experiments it is possible to detect the presence of a magnetic field around a current-carrying conductor. For example:

:: When a wire carrying a current is buried in iron filings and then lifted, some of the filings will cling to its surface. When the current passing through the wire is increased and the experiment repeated, more filings cling to the wire. When the current flow ceases the filings fall from the wire.

:: When the same piece of wire is passed through a hole in a horizontal piece of cardboard and iron filings are sprinkled on the card, the iron filings will form a pattern of concentric rings when current flows and the card is tapped, (Fig. 35a). A compass placed on the card will indicate the direction of the magnetic field and if the current is reversed the field reverses (Fig. 35b).



(a) Field Pattern. (b) Compass Needle Deflects.

FIG. 35. THE MAGNETIC FIELD DUE TO ELECTRIC CURRENT.

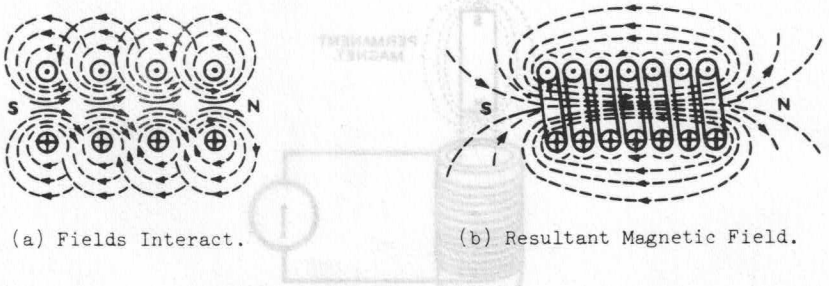
The results of these experiments can be summarised as follows:

:: the strength of the magnetic field around a current-carrying conductor depends upon the value of the current;

:: the field takes the form of concentric rings in a plane at right angles to the conductor;

:: the direction of the magnetic field depends upon the direction of the current.

14.14 MAGNETIC FIELD OF A SOLENOID. A solenoid consists of numerous turns or windings of insulated wire wound close together in the form of a coil. When current flows in a solenoid, the magnetic field produced by each turn interacts with the field produced by adjacent turns, as shown in Fig. 36a. Within the solenoid the lines of force are in the same direction so that the resultant field is as shown in Fig. 36b. This corresponds with the field pattern of a bar magnet, possessing a North pole where the lines of force leave the coil, and a South pole where they enter.



(a) Fields Interact. (b) Resultant Magnetic Field.

FIG. 36. MAGNETIC FIELD OF A SOLENOID.

The strength of the magnetic field in a solenoid depends upon the number of turns or windings in the coil and the value of the current flowing. An increase in either of these, results in an increase in magnetic field strength. The strength of the magnetic field can also be increased by the inclusion of an iron core in the coil, which has the effect of concentrating the magnetic field.

14.15 TERMS USED IN MAGNETISM. In the study of magnetism, certain terms are commonly used to describe the quantities and conditions that exist. These terms are applicable to all types of magnetic fields, irrespective of whether they are produced by permanent magnets or electromagnets.

14.16 MAGNETIC FLUX. The total number of lines of force entering or leaving the pole of a magnet is called the magnetic flux. The same term can be applied to the total number of lines of force induced into a magnetic material.

The symbol for magnetic flux is the Greek letter "phi", which is written as d.

14.17 FLUX DENSITY. The flux density of a magnetic material is a measure of the magnetic flux per unit area, measured at right angles to the direction of the magnetic field. The symbol for flux density is B.

14.18 MAGNETOMOTIVE FORCE. The total force which establishes and maintains a magnetic flux is called the magnetomotive force the symbol for which is F.

Magnetomotive force is measured in terms of the force produced when an electric current flows in a conductor. When the conductor is formed into a coil, the magnitude of the force depends upon the value of the current, and the number of turns. The product of these quantities is often expressed in 'ampere-turns'.

14.19 MAGNETISING FORCE. Magnetising force is the term used to express the intensity of the magnetising field applied to a material, the symbol is H.

14.20 RELUCTANCE. Is the opposition offered by a material to the establishment of a magnetic flux. The symbol for reluctance is R.

15. INDUCED E.M.F's AND CURRENTS

15.1 Faraday's experiments investigated the relationship between electricity and magnetism, and resulted in the formulation of his law of electromagnetic induction, which is stated as follows:

When relative motion exists between a magnetic field and a conductor, an e.m.f. is induced into the conductor, and when the circuit is closed a current flows.

For example, Fig. 37 shows a coil of wire wound on a circular former; the ends of the coil are connected to a sensitive centre zero electrical instrument. When the north pole of a bar magnet is inserted into the middle of the tube, the instrument needle is immediately deflected to one side, and then returns to zero. When the magnet is withdrawn, the needle is again deflected, but in the opposite direction, and again returns to zero.

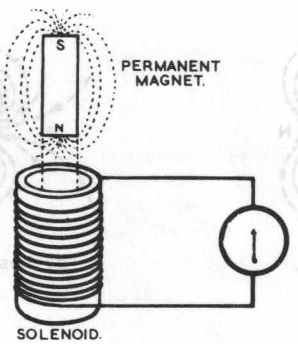


FIG. 37. RELATIVE MOVEMENT INDUCES AN ELECTRICAL CURRENT.

The principle of this action is that the magnetic field moves with the magnet, and when the magnet is inserted into the coil, the lines of force comprising the magnet's field, link or cut the turns of the coil. This cutting sets up an induced e.m.f. across the coil, and the resultant current passes through the completed circuit of coil and meter.

The current only occurs when the magnet or coil is in motion; if the magnet or coil comes to rest, the current stops.

The value of induced e.m.f. and resultant current flow is dependent upon:

:: the field strength of the magnet; the stronger the field, the greater is the induced effect;

:: the number of turns on the coil; an increase in turns increases the induced effect;

:: the speed of cutting; the faster the relative motion, the greater is the induced effect.

Remember, the induced effect is only transient; and exists only while the magnet or coil moves.

15.2 When an energised electromagnet is substituted for the permanent magnet, as shown in Fig. 38, similar results are obtained.

Further, when the electromagnet is placed in the coil and the means (for example, a switch) provided to stop and start the current through the electromagnet, a current is induced in the coil without movement of the electromagnet.

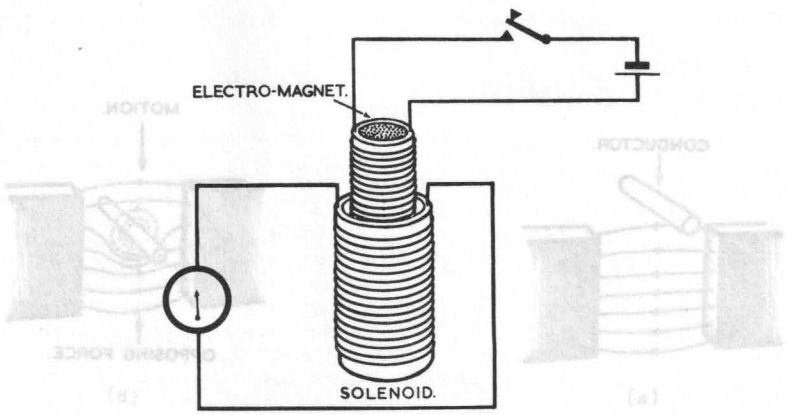


FIG. 38. ANOTHER METHOD OF INDUCING AN ELECTRIC CURRENT.

The closing of the ciruit of the electromagnet allows current to flow. This current creates a magnetic field, and as the lines of force are established and expand, they cut the turns of the coil. When the circuit of the electromagnet is opened, the field collapses and the lines of force cut across the turns of the coil in the opposite direction.

As we shall see later, this principle is utilised in an induction coil or transformer, the coil of the electromagnet acting as the primary circuit and the other coil as the secondary circuit.

15.3 We can summarise these effects in the following way.

An induced e.m.f. will occur when:

:: relative motion occurs between a magnet and a coil;

:: relative motion occurs between an energised electromagnet and a coil;

:: the current in an electromagnet is stopped, started or varied.

The magnitude of the induced effect varies the strength of the magnetic field and the rate of movement.

15.4 LENZ'S LAW. We have seen that relative motion between lines of force and a conductor produces an induced e.m.f., and if the circuit is closed, a current. However, examination of the following conditions show that the magnetic effect of the induced current tends to oppose the originating motion.

With the conductor at rest, there is no induced effect, and no magnetic field around the wire, the only field present being due to the permanent magnet (Fig. 39a).

When the wire is moved downwards into the permanent magnet's field, an e.m.f. is induced, and the flux produced by the resultant current, combines with the magnet's field to produce a magnetic effect which opposes the motion of the conductor into the field (Fig. 39b).

From similar experiments, Lenz, a Russian physicist, formulated his law which is expressed as follows:

Induced currents (and e.m.f's) are always in such a direction that their effects tend to oppose the motion which produces them.

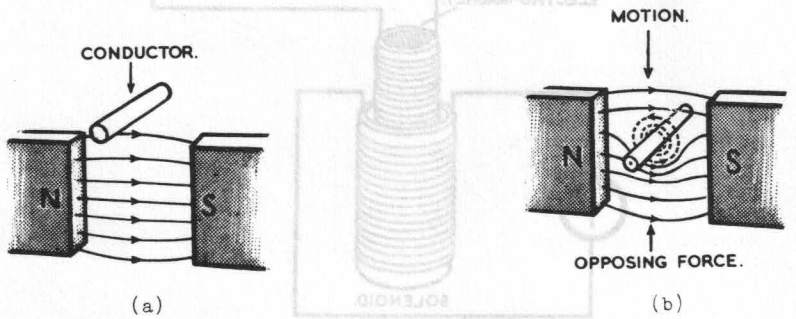


FIG. 39. PRINCIPLE OF LENZ'S LAW.

16. GENERATORS AND MOTORS.

16.1 A.C. GENERATOR. This generator (sometimes called an alternator) uses the principle of induction, in as much as a coil of wire is mechanically rotated in a field produced by a permanent magnet or electromagnet. As the coil rotates, it cuts the magnetic field and an alternating voltage is induced across the coil. When the coil is connected to a closed circuit, current flows.

16.2 Fig. 40 shows how A.C. current is generated by the rotation of a single turn of wire in a magnetic field, with connection made from the coil to the external load by slip rings and brushes. The direction of current flow is shown at the various positions of the coil of wire.

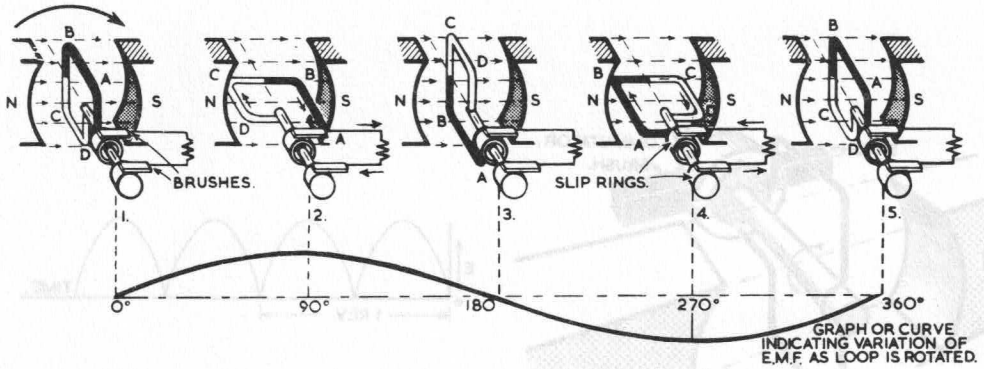


FIG. 40. HOW THE GENERATOR GENERATES CURRENT.

In positions 1, 3 and 5, both sides of the turn are moving parallel with the lines of force and, therefore, do not cut the field. In this position there is no induced e.m.f.

At positions 2 and 4 the turn has both sides cutting the field at right-angles. E.M.F's in series are induced across the two sides of the turn, so that current flows in the external circuit. The voltage increases gradually from zero at 1 to a maximum at 2. This is because the sides of the turn cut a gradually increasing number of lines per unit time as the turn rotates.

The graph shows the variation in the value and direction of the induced e.m.f., and, therefore, the voltage applied across the external circuit for one complete cycle or revolution of the armature;

16.3 In practice, the single loop of wire shown in the diagram is replaced by a coil of many turns of insulated wire, wound upon a soft iron core, called an amature, which is turned by a handle or motor.

E.M.F's are generated in each turn of the coil, and so the total e.m.f. produced by the generator is increased in direct proportion to the number of turns. Thus, for the same speed of rotation, a generator with a coil of ten turns generates ten times the e.m.f. of a similar machine with only a single loop.

The iron core increases the induced e.m.f. by increasing the intensity of the magnetic field in which the coil rotates.

16.4 DIRECT CURRENT GENERATOR. The D.C. generator operates on the same principle as the A.C. generator, but uses a device called a commutator to convert the induced A.C. of the armature so that a D.C. flows in the external circuit. The generator consists of conductors rotating in a magnetic field, but the coil, instead of being connected to slip rings as in an alternator, is joined to the two halves of a split ring which is mounted on, but insulated from the generator shaft (Fig. 41a).

The split ring is termed a commutator, and acts as an automatic reversing switch which reverses the coil's connections to the external circuit each time the coil current reverses.

The current pick-up and connection to the external circuit is made by brushes, usually of carbon, which are mounted in such a position to the magnetic field, that the connection changes from one commutator segment to the other when the coil current is zero.

The output from this generator is unidirectional, but pulsating (Fig. 41b), the speed of pulsations being determined by the speed of the generator.

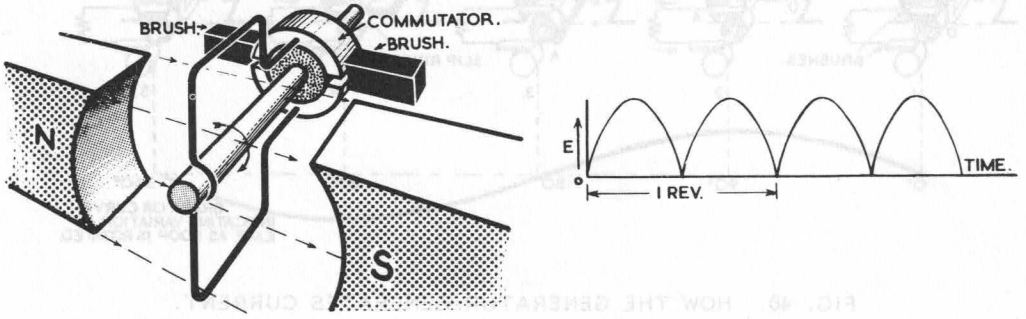


FIG. 41. SIMPLE COMMUTATION.

17. PRIMARY AND SECONDARY CELLS.

17.1 PRIMARY CELL. A steady flow of electricity was first produced in 1799 by chemical action in the Voltaic cell.

In a simple primary cell of this type, an e.m.f. is produced by placing two dissimilar electrodes in a chemical solution. The value of the e.m.f. is dependent on the type of dissimilar electrodes and the nature of the solution.

The following table shows approximate values of e.m.f. from various combinations of electrodes and solutions:

ELECTRODES	SOLUTION	APPROXIMATE E.M.F.
Copper and Carbon	Sulphuric Acid	0.25 volts
Carbon and Zinc	Sulphuric Acid	1.5 volts

TABLE 4. E.M.F. OF PRIMARY CELLS.

The pieces of carbon, copper, zinc, etc., are called plates or electrodes and the solution is termed the electrolyte. In commonly used primary cells, the electrodes are carbon and zinc and the electrolyte is ammonium chloride (Fig. 42).

In the simple cell shown in Fig. 42 the negative terminal is zinc and the positive terminal is carbon.

While the electrodes of the simple cell shown in Fig. 42 are disconnected externally no current flows, but when the circuit is closed, by connecting a lamp to the terminals a discharge current will flow from the cell through the lamp. The current consists of electrons which pass from negative terminal to positive terminal (election flow) however conventional current is always used and therefore the current is said to flow in the external circuit from positive to negative.

17.2 CHEMICAL ACTION. When the zinc and carbon electrodes are immersed in the electrolyte, a chemical action takes place, and the electrodes take up a potential difference to each other of about 1.5 volts; the zinc electrode being negative polarity with respect to the carbon electrode.

When the external circuit is closed electrons will flow through the load as a result of the p.d. between the electrodes.

The chemical action which result in current flow produce a visible change in the components within the cell; they are:

:: the zinc electrode is progressively eaten away.

:: hydrogen bubbles form around the carbon electrode.

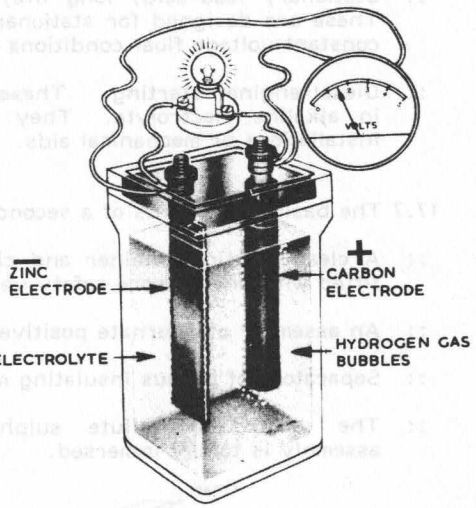


FIG. 42. SIMPLE PRIMARY CELL

17.3 TYPES OF PRIMARY CELLS. Primary cells are available in many forms and some examples are shown in Fig. 43.

FIG. 43. TYPICAL PRIMARY CELLS.

17.4 SECONDARY CELLS. Batteries of secondary cells provide a low impedance source of power and are installed at all telephone exchanges as a standby source of power. The batteries are maintained in a fully charged condition while the primary source of power is available and are used to supply power to the equipment when the primary source of supply fails.

17.5 Secondary batteries convert electrical energy into chemical energy during charging and the procedure is reversed during discharge. The cycle of charge and discharge can be repeated throughout the life of the battery. When the cell is charged it exhibits an e.m.f. of 2.1 volts.

17.6 Two types of secondary cells are used in Telecom:

:: Stationary lead-acid, long life, pure lead positive plate type. (See Fig. 44). These are designed for stationary use. They are best suited for operation under constant voltage float conditions which ensure long cell life.

:: Diesel-engine starting. These may be either lead-acid, or nickel-cadmium in alkaline electrolyte. They are used for starting standby plant in Telcom installations or mechanical aids.

17.7 The basic components of a secondary cell comprise:

:: A clear plastic container and clear or opaque lid or a hard rubber case and lid fitted with one or more safety vents.

:: An assembly of alternate positive and negative plates.

:: Separators of porous insulating material between the plates.

:: The electrolyte; dilute sulphuric acid in which the plate and separator assembly is totally immersed.

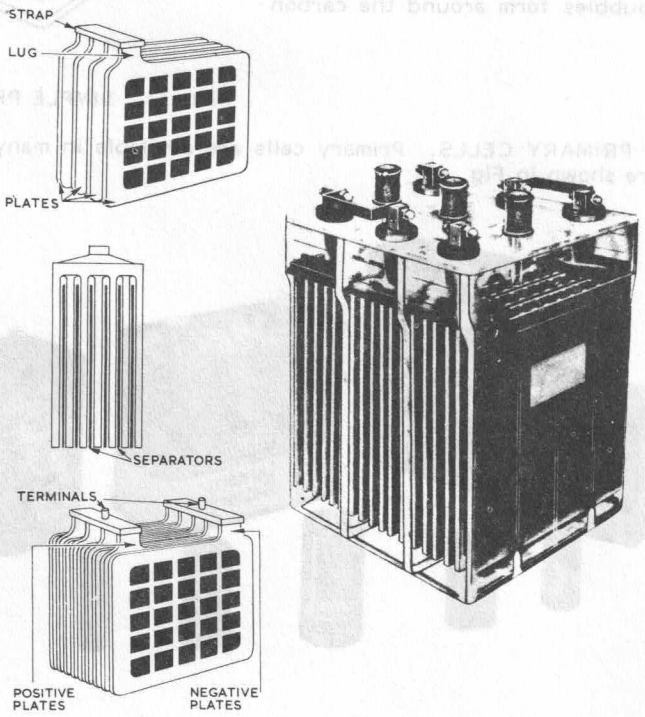


FIG. 44. 6 VOLT SECONDARY CELL, ENCLOSED TYPE, CLEAR PLASTIC CONTAINER.

17.8 GROUPING OF DRY CELLS. In communication circuits, cells are connected either in series or parallel, to increase the e.m.f. or current in the circuit. As a cell is both a source of e.m.f. and a resistance, the method of connecting of a number of cells comprising a battery, will affect both the e.m.f. and resistance of the battery.

17.9 CELLS IN SERIES, connect the positive terminal of one cell to the negative terminal of the next cell, and so on. Fig. 45 illustrates a battery of four cells connected in series. If the e.m.f. of each cell is 1.5 volts, then the battery as a whole has an e.m.f. of 6 volts. Cells (and batteries) of different e.m.f.'s can be connected in series, for example 2 volt cells can be connected in series with 1.5 volt cells.

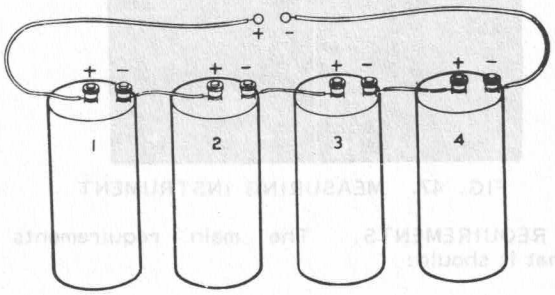


FIG. 45. CONNECTION OF CELLS IN SERIES.

17.10 CELLS IN PARALLEL, connect all positive terminals to a single wire, and all negative terminals to another wire. Fig. 46 shows a battery of four cells (each with the same e.m.f.) connected in parallel. This gives the equivalent of one large cell. The e.m.f. of the battery is still the same as the e.m.f. of one cell. Under working conditions each cell will supply one quarter of the total current.

Cells (and batteries) should not be connected in parallel unless their e.m.f.'s are the same, as those with higher e.m.f.'s discharge through those with lower e.m.f.'s.

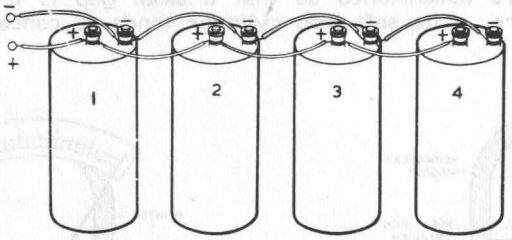


FIG. 46. CONNECTION OF CELLS IN PARALLEL.

18. D.C. AND A.C. MEASUREMENTS.

18.1 MEASURING INSTRUMENTS. An electrical measuring instrument is a device used for determining, and displaying in a suitable manner, the magnitude of an electrical quantity.

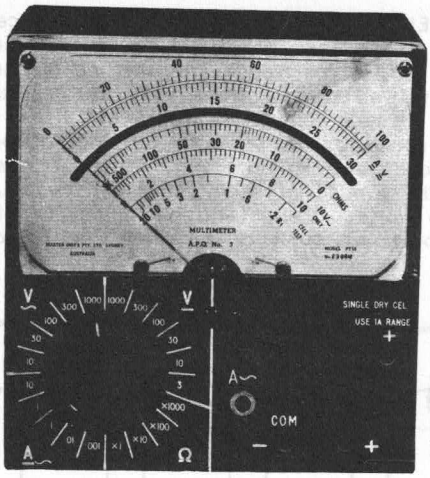


FIG. 47. MEASURING INSTRUMENT

18.2 INSTRUMENT REQUIREMENTS. The main requirements of a measuring instrument are that it should:

:: Be easy to operate and read.

:: Provide accurate readings as quickly as possible.

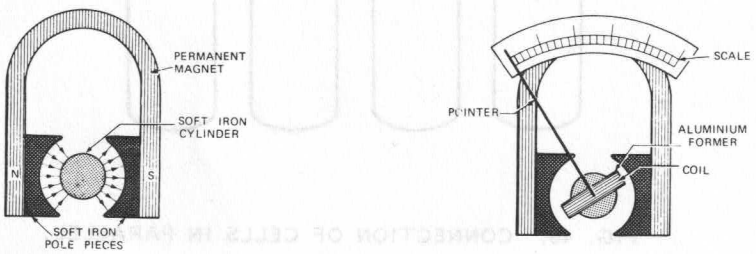
:: Have minimum effect on the circuit when connected for measurement.

:: Be self-protecting.

:: Be safe to use.

18.3 THE MOVING COIL INSTRUMENT is one of the most commonly used instruments. It is the basic component (sometimes referred to as the movement) of many measuring instruments.

18.4 CONSTRUCTION. A movement consists of a permanent magnet with soft iron pole pieces providing a circular air gap (Fig. 48a). Centred in the air gap is a cylindrical soft iron core dimensioned so that a small gap is left between the pole pieces and the iron core. The soft iron cylinder tends to concentrate the magnetic field.



(a) Radial Field (b) Constructional Details

FIG. 48. MOVING COIL METER.

A light rectangular coil of fine wire is wound on to a non-magnetic former, and mounted so that it is free to pivot in the air gap and magnetic field of the magnet assembly (Fig. 48b). Attached to the coil is a light pointer which moves over a scale graduated in the units to be measured.

The pivots rest on jewelled bearings and the energising current is led to and from the coil by two light spiral springs, (Fig. 49a). One end of each spring is attached to the frame of the instrument, and the other end to the moving coil. The springs also provide the opposing force against which the moving coil acts, and serve to return the pointer to zero.

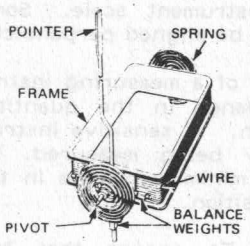
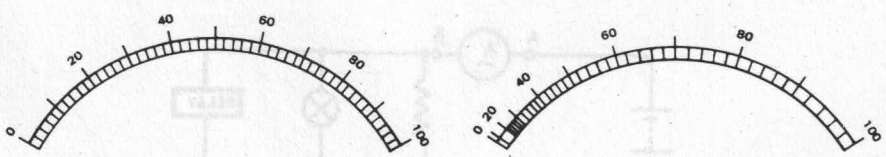


FIG. 49. COIL ASSEMBLY AND SPRINGS.

18.5 OPERATION. The movement uses the 'motor principle' of a current-carrying wire in a magnetic field. When current flows through the coil, an interaction occurs between the field of the magnet and the field of the moving coil. This produces a force which turns the coil in its axis against the force exerted by the springs. When the electrical and mechanical forces are equal, rotation stops, and the pointer indicates the reading on a graduated scale. The pointer moves in a somewhat slow motion, called a 'damped' movement, to its final steady deflection, which enables a reading to be taken immediately.

18.6 MEASURING INSTRUMENT TERMS. Before proceeding with electrical measurements it is essential that you understand the terms used in conjunction with measuring instruments. Terms commonly used with pointer type instruments follow.

18.7 SCALE. The series of marks and numbers on the dial of an instrument is referred to as the 'scale' (Fig. 50). The scale may be linear or non-linear, depending on the type of meter and the relationship between the quantity sensed and the units in which the scale is marked. A linear scale is one in which a given length of scale represents the same magnitude throughout the whole scale length (Fig. 50a) A non-linear scale is one in which the allocation of scale length is not uniform (Fig. 50b). Linear scales are preferred because they are easier to read. Note that the scale is divided into a number of 'scale divisions'.



(a) Linear Scale (b) Non-linear Scale

FIG. 50. LINEAR AND NON-LINEAR SCALES.

18.8 RANGE. The range of a measuring instrument indicates the values which the instrument is capable of measuring. For example, if a voltmeter has a range of 0-1000V it is capable of measuring voltages between the figures stated, that is, between 0 and 1000 volts.

18.9 CALIBRATION is the name given to the process of checking the relationship between the values of the electrical quantity applied to an instrument and the corresponding positions of the indicating device (pointer, etc.). It ensures that an instrument is capable of measuring electrical quantities with the accuracy stated by the manufacturer.

18.10 PARALLAX ERROR is the name given to errors which are caused by the eye not being perpendicular to the instrument scale. Some instruments have mirror inserts in the dial to enable the eye to be aligned perpendicularly above the pointer.

18.11 SENSITIVITY. The sensitivity of a measuring instrument gives an indication of the relationship between a change in the quantity being measured and the consequent change in pointer position. A sensitive instrument is one which responds to a small change in the quantity being measured. When designing a sensitive instrument, the designer aims for a minimum change in the quantity to be measured, causing maximum change in pointer position.

18.12 CURRENT MEASUREMENTS. To ensure that telecommunications equipment operates correctly, and that maximum current values are not exceeded, it is often necessary to measure the value of current in a circuit. In such a case, a measuring instrument called an ammeter is connected in series with the current path (Fig. 51). Connecting the ammeter in series with the circuit ensures that all of the current to be measured flows through the ammeter.

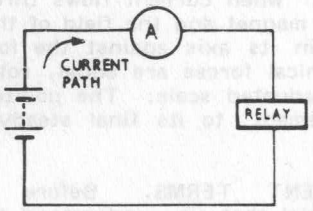


FIG. 51. AMMETER CONNECTION.

Fig. 52. shows a series-parallel circuit comprising a series resistor, and a relay connected in parallel with a lamp and a resistor. To measure the total current in the circuit the ammeter must be connected between points which carry the total circuit current. In this case, the ammeter is connected between points A and B.

To measure only the current via the relay, the ammeter is connected between terminals G & H. Similarly, the current through the lamp or resistor is measured by using terminals EF, or CD, respectively.

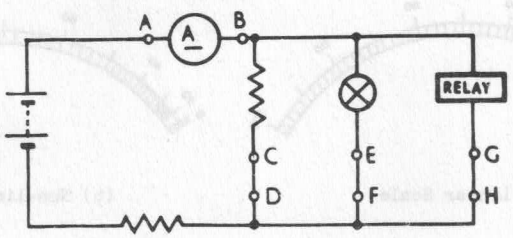


FIG. 52. MEASURING CURRENT.

18.13 POLARITY OF CONNECTION FOR D.C. MEASUREMENTS. With moving coil ammeters the direction in which the pointer is deflected is dependent on the direction of the current through the moving coil. Since most ammeters are designed with the zero current point at one end of the scale, it is necessary to ensure that current is passed through the moving coil in a particular direction. For this reason the terminals are designated, and the positive terminal should be connected to the more positive side of the circuit and the negative terminal to the more negative side (Fig. 53).

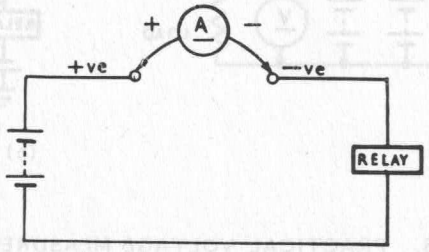
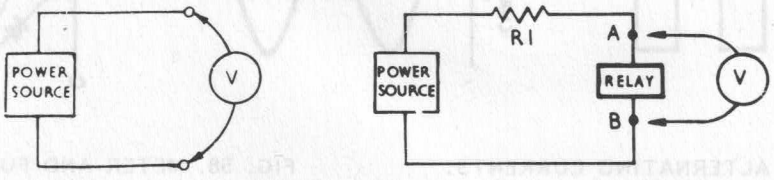


FIG. 53. D.C. AMMETER CONECTIONS.

18.14 VOLTAGE MEASUREMENTS. Voltage measurements are often made during the installation and maintenance of communications equipment. Two common situations in which voltages are measured, are the measurement of the voltage of a power source (Fig. 54a), and the measurement of the voltage across a component or network connected to a power source (Fig. 54b). In both cases the measuring instrument is connected across the points between which the voltage is to be measured. In other words, the measuring instrument is placed in parallel with the power source, the component, or the network.



(a) Voltage of power source (b) Voltages across a component

FIG. 54. TYPICAL VOLTAGES TO BE MEASURED.

The instrument most frequently used to measure voltage is referred to as a voltmeter. Fig. 55 shows a series parallel circuit comprising a series resistor, and relay connected in parallel with a lamp and resistor. To measure the voltage supplied by the power source (battery) a voltmeter is connected directly across its terminals (points A and B). To measure the voltage across the series resistor R1 the voltmeter is connected in parallel with the resistor (points C and D). However as the voltages across the relay, the lamp and resistor R2 are all of the same value, the voltage across these components is measured by connecting the voltmeter between points E and F.

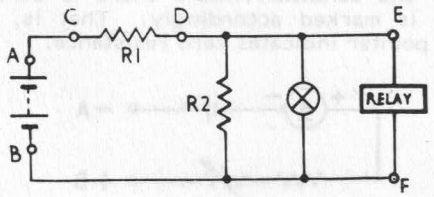


FIG. 55. VOLTAGE MEASURING POINTS

Figs. 56a and 56b show voltage readings being made in two practical situations. In Fig. 56a, the voltmeter is measuring the voltage being supplied from a d.c. power installation. In Fig. 56b a voltmeter is being used to check the continuity of the coil in a relay set.

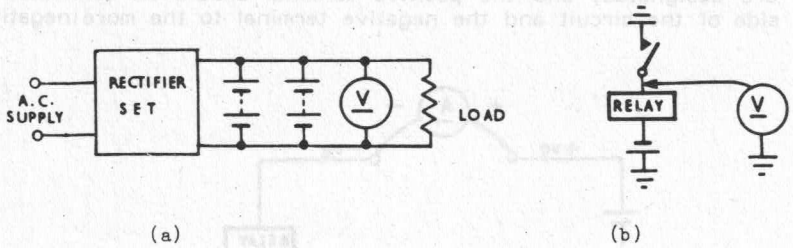
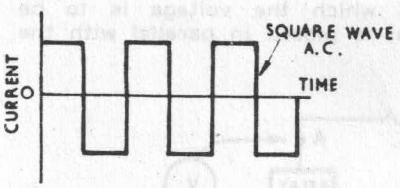


FIG. 56. PRACTICAL VOLTAGE MEASUREMENTS.

18.15 ALTERNATING CURRENT MEASUREMENTS. In previous paragraphs the measurement of unidirectional, or direct current has been considered. In many situations it is necessary to measure reversing, or alternating, current. Fig. 57. compares graphical representations of two forms of alternating current (a.c.).



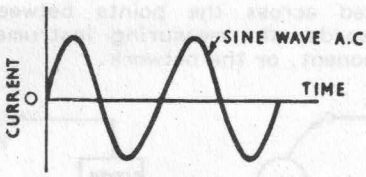


FIG. 57. ALTERNATING CURRENTS.

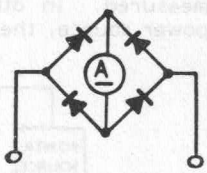


FIG. 58. METER AND FULL-WAVE RECTIFIER.

When the currents represented in Figs. 57. pass through a moving coil instrument, a zero reading results. This is because the pointer cannot follow the fast changes in current direction and tend to settle at a point half way between the two extreme values; that is, zero current. To use the instrument to measure a.c., the current through the moving coil must be converted to d.c., by the use of the full-wave rectifier built into the meter circuit as shown in Fig. 58.

18.16 OHMMETER. Fig. 59a shows the basic operating principle of an ohmmeter. A moving coil ammeter is connected in series with a battery, a fixed resistor, and a variable resistor. The circuit components are selected so that when terminals (A and B) are short-circuited, a full scale deflection of the pointer can be obtained by varying the circuit current under the control of the variable resistor. The full scale deflection corresponds to the condition where there is zero resistance between the terminals, and the scale is marked accordingly. That is, the full scale deflection position of the instrument pointer indicates zero resistance.

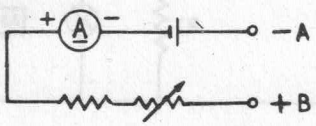


FIG. 59. OHMMETER.

When an unknown resistance is connected between the ohmmeter terminals, the circuit current is reduced and the pointer takes up a position which is less than a full scale deflection. Because the circuit voltage is constant and the circuit current and the deflection of the pointer are dependent on the value of the unknown resistance, the scale is set out directly in ohms.

The range of resistances that can be read is extended by changing the value of the fixed resistor. In the case of very high resistances, it may be necessary to increase the battery voltage in order that sufficient current flows via the moving coil to produce a full scale deflection when the terminals are short-circuited.

18.17 RESISTANCE MEASUREMENTS USING AN OHMMETER. To measure resistance with an ohmmeter the instrument terminals are connected across the unknown resistance.

Because false readings are obtained if current via the moving coil is drawn from any source other than the internal battery, it is essential that ohmmeters are used on circuits after power supplies are either switched off or disconnected.

It is also essential to check that only the relevant component or circuit is connected between the ohmmeter terminals. When other parallel paths exist a false reading will be obtained.

18.18 MULTIMETERS. The multimeter is one of the most commonly used measuring instruments, since it can be used to measure current, voltage and resistance. A wide range of multimeters are used by Telecom, with A.P.O. No. 3 (Fig. 60) being used as a general purpose instrument.

18.19 THE A.P.O. NO. 3 MULTIMETER is self-contained and designed for use in the face upward position. The multimeter is housed in a bakelite case and the batteries required for resistance measurements are located in a moulded recess with a removable cover in the rear of the case. It has accuracy of better than 1% of the full scale value on d.c. ranges.

Components are switched into circuit as required to enable the meter to make measurements within the following ranges:

D.C.		A.C.	
CURRENT	VOLTAGE	CURRENT	VOLTAGE
0-1 mA	0-3 V	0-1 mA	0-10 V
0-10 mA	0-10 V	0-10 mA	0-30 V
0-100 mA	0-30 V	0-100 mA	0-100 V
0-1 A	0-100 V	0-1 A	0-300 V
0-10 A	0-300 V	0-10 A	0-1000 V
	0-1000 V		

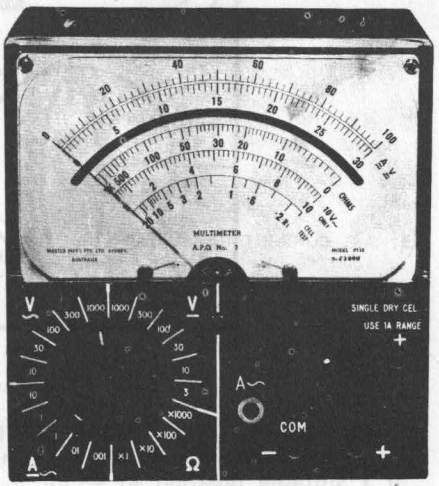


FIG. 60. A.P.O. NO. 3 MULTIMETER.

Fig. 61 shows the face layout of the meter comprising the scale, the operating controls, and test jacks for the connection of test leads. The scale has a mirror insert to reduce parallax errors. The operating controls comprise a twenty position rotary switch, a variable resistor, and a zero adjuster. The rotary switch moves through a full circle which is divided into a four sectors. Each sector is further subdivided to provide the required number of positions. The variable resistor is used when making resistance measurements, and the zero adjuster allows mechanical adjustment of the pointer position when the meter is in the rest condition. Four test jacks are used as required to make connections via test leads to the network or component under test.

18.20 D.C. VOLTAGE MEASUREMENTS. To measure d.c. voltages the test leads are inserted in the -(com) and + test jacks, Sector 1 of the range switch is associated with d.c. voltage measurements and is further divided into six separate ranges. The 0-30 and 0-100 scale markings are used as required for all d.c. voltage measurements.

18.21 A.C. VOLTAGE MEASUREMENTS. To measure a.c. voltages, the test leads are inserted in the - (com) and + test jacks, and the range switch is operated to a suitable position in sector 2. The 0-30 and 0-100 scale markings are used for all readings except those associated with the 10 V position of the range switch. For this range a special 0-10 scale is used.

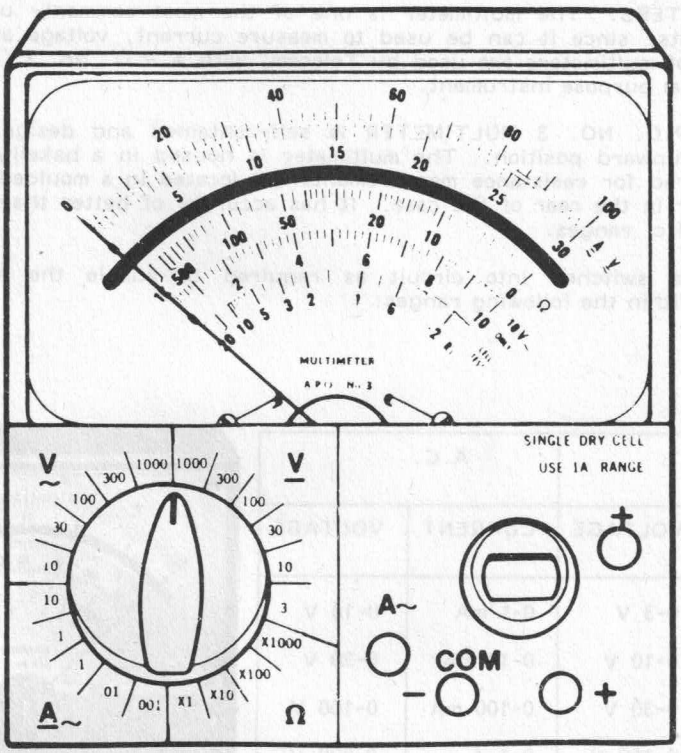


FIG. 61. FACE LAYOUT OF A.P.O. NO. 3.

18.22 D.C. CURRENT MEASUREMENTS. To measure d.c. current, the test leads are again inserted in the - (com) and + test jacks, and the range switch is operated to a suitable position in sector 3. All current measurements are taken from the 0-100 scale. For example, with the range switch on .001, a full scale deflection indicates 1 mA.

18.23 A.C. CURRENT MEASUREMENTS. For a.c. current measurements the leads are inserted in - (com) and A-. Sector 3 of the range switch is used for A.C. current measurements which are all taken from the 0-100 scale.

18.24 RESISTANCE MEASUREMENTS. To measure resistance, the test leads are inserted in - (com) and +, and the range switch is operated to a suitable position in sector 4. The various positions in sector 4 are designated by a multiplying factor which is used together with the ohms scale reading to determine the resistance value. For example, if the range switch is in the x100 position and the scale reading is 20, then the resistance between the terminals is 20 x 100 = 2000 ohms. The variable resistor used to set the zero ohms point must be adjusted before taking a reading, and after each alteration of the position of the range switch. Because the scale is cramped at the high end, resistance measurements should be made on the ohms range which gives a reading on the scale of between 5 and 50.

18.25 READING METER SCALES. The entire range of a meter scale is divided into a number of divisions. The main divisions are usually numbered, but some numbers may be omitted to make the dial easier to read. Each main division is divided into a number of smaller parts or spaces.

There may be several scales on the dial when the meter is used for different ranges. The range of a meter means the highest value on the particular scale. Care must be taken when reading these meters, to interpret the reading with relation to the selected range or scale only.

18.26 Practice the skills of reading instrument scales by answering the questions posed by the examples shown. Example No. 1. The diagram shows the meter scale on a moving coil milliammeter which has a range of 0-150mA.

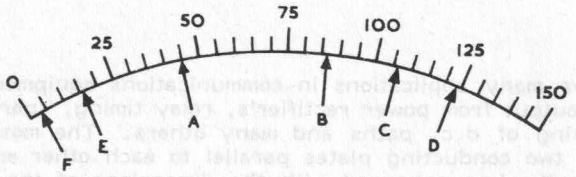


FIG. 62. D.C. MILLIAMETER.

(i) What is the value of each small space between the main divisions?

(ii) What is the meter reading indicated by arrow A?

(iii) What is the meter reading indicated by arrow B?

18.27 Example No. 2. Find the reading indicated by arrow A for each scale of the dial shown in the diagram.

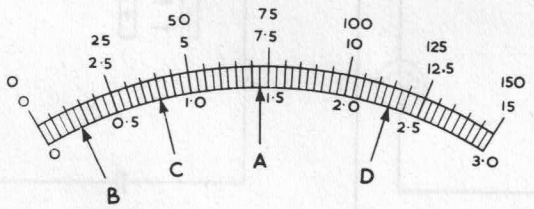


FIG. 63. D.C. VOLTMETER.

1. Referring to the diagram in Example No. 2, the meter reading indicated by:

(i) Arrow B on the 15V scale. ..... Volts.

(ii) Arrow C on the 3V scale. ..... Volts.

(iii) Arrow D on the 150V scale. ..... Volts.

2. Referring to the following diagram, what is the meter reading for each scale, at the points indicated by the arrows?

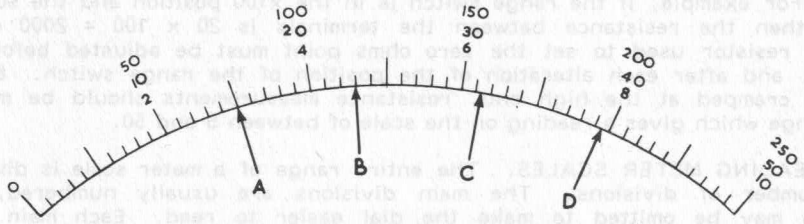


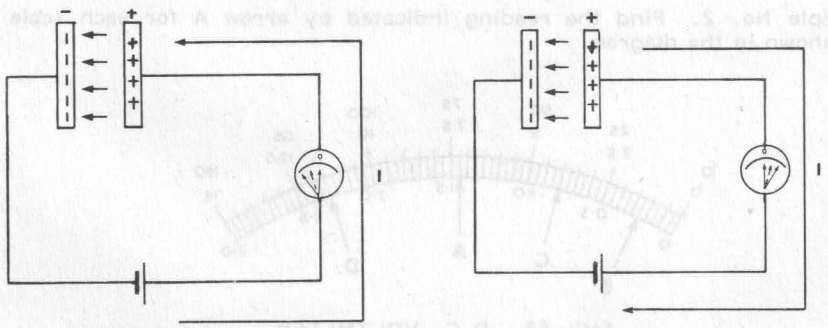
FIG. 64. D.C. MILLIAMMETER.

	10mA scale	50mA scale	250mA scale
A			
B			
C			
D			

19. CAPACITORS.

19.1 Capacitors have many applications in communications equipment. They include 'smoothing' of output from power rectifier's, relay timing, spark quenching when contacts open, blocking of d.c. paths and many others. The most common type of capacitor consists of two conducting plates parallel to each other and separated by a distance which is small when compared with the dimensions of the plates. The gap between the plates may be air or consist of an insulating material called the 'dielectric.'

When a potential is connected between the plates (Fig.65a) the plates become charged to positive and negative potentials. This produces a uniform electric field between the plates. When the potential used to charge the plates is removed the capacitor will store the charge. To discharge the capacitor it is necessary to provide an external circuit between the plates and current will flow in the opposite direction until the two plates are at equal potential (Fig. 65b)



(a) CHARGE (b) DISCHARGE

FIG. 65. CAPACITOR CHARGE AND DISCHARGE.

19.2 THE UNIT OF CAPACITANCE. Capacitance is defined as the ratio of the charge of a capacitor to the p.d. between its plates. The unit of capacitance is the Farad, Symbol F. A capacitor is said to possess a capacitance of one farad when a charge of one coulomb raises the potential difference between the plates by one volt.

Submultiple Units. A capacitor possessing a capacitance of one farad is too large both physically and electrically to be of practical use in electrical circuits. Because of this the following submultiple units are normally used:

:: Microfarad (symbol μF), $1\mu F = 1 \times 10^{-6}$

:: Picafarad (symbol pF), $1pF = 1 \times 10^{-12}$

19.3 Capacitors are classified as fixed or variable, with a further classification being made according to the type of dielectric material. The large range of capacitors available results from differences in the ratings and applications required, and from the variety of materials and construction used.

Fig. 66 shows symbols for fixed and variable capacitors and Fig. 67 illustrates some common types of capacitors used in Telecom.

FIG. 66. CAPACITORS SYMBOLS.

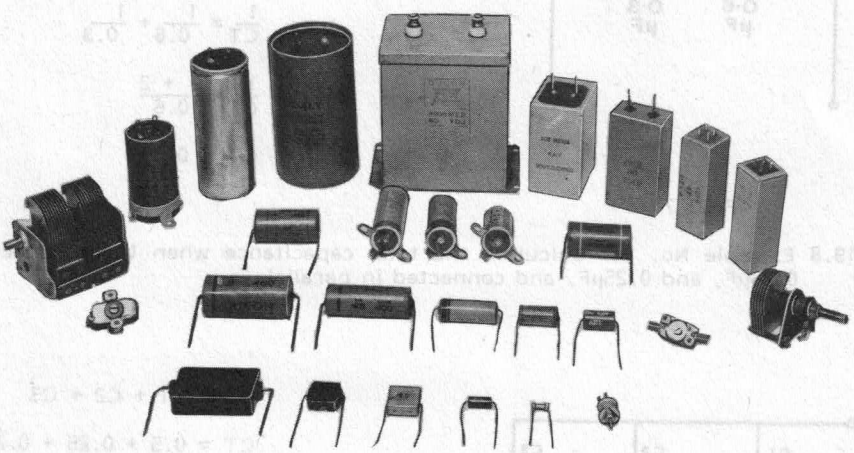


FIG. 67. CAPACITORS USED IN TELECOM.

19.4 CAPACITORS IN SERIES AND PARALLEL. When capacitors are connected in series or parallel the method of finding the total capacitance is opposite to that used when finding the total resistance of series or parallel resistors.

19.5 CAPACITORS IN SERIES. Fig. 68 illustrates that connecting capacitors in series effectively increases the dielectric space, which decreases the total capacity to less than the smallest capacity in the combination.

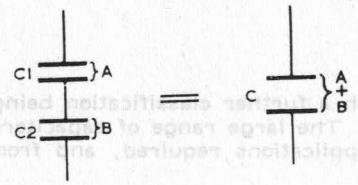


FIG. 68

Formula for two capacitors in Series

$$C = \frac{C1 \times C2}{C1 + C2}$$

or

$$\frac{1}{CT} = \frac{1}{C1} + \frac{1}{C2}$$

19.6 CAPACITORS IN PARALLEL. When capacitors are connected in parallel, the effect produced is one large capacitor with a plate area equal to the sum of the plate areas of the component capacitors. (Fig. 69).

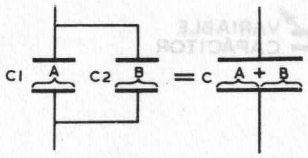


FIG. 69.

Formula for capacitors in Parallel.

$$CT = C1 + C2 + C3$$

19.7 Example No. 1. Calculate the total capacitance when two capacitors of 0.6 μF, and 0.3 μF, are connected in series.

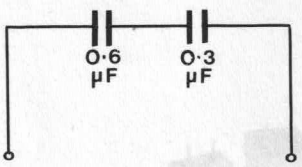


FIG. 70

$$\frac{1}{CT} = \frac{1}{C1} + \frac{1}{C2}$$

$$\frac{1}{CT} = \frac{1}{0.6} + \frac{1}{0.3}$$

$$\frac{1}{CT} = \frac{1 + 2}{0.6}$$

$$CT = 0.2\mu F$$

19.8 Example No. 2. Calculate the total capacitance when three capacitors of 0.5μF, 0.25μF, and 0.25μF, and connected in parallel.

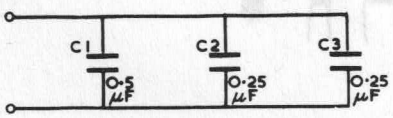


FIG. 71.

$$CT = C1 + C2 + C3$$

$$CT = 0.5 + 0.25 + 0.25$$

$$CT = 1\mu F$$

20. INDUCTANCE

20.1 SELF INDUCTANCE AND INDUCTANCE. Having considered the induced effect produced by one coil on another; let us examine the induced effects produced in a circuit consisting of a single coil.

When a source of e.m.f. is applied to a coil, and current flows in the coil, the resulting magnetic flux rises and links the turns of the coil, inducing across its turns an e.m.f. which, will be in opposition to the applied e.m.f. When the current reaches the Ohm's law value, the flux becomes stationary and the induced effect disappears.

This effect of a current, changing in a coil or conductor, and inducing an e.m.f. in reverse to that applied, is termed self induction. The induced e.m.f. is sometimes termed the back e.m.f., and as a result, the current rise from zero to the final steady value takes a certain time in this type of circuit.

When the circuit is opened the flux collapses and dissipation of the electrical energy produced by induction can be observed, as the self induced e.m.f. produces a spark across the switch contacts when they open.

20.2 The property of any electric circuit, by which a voltage is induced in the circuit when the current is started, stopped or changed in value is called inductance.

20.3 UNIT OF INDUCTANCE. The unit of inductance is the Henry, and a circuit has an inductance of 1 Henry when a current with a rate of change of one ampere per second induces in it an e.m.f. of one volt.

20.4 INDUCTORS. An inductor is a device which has been constructed so that it possesses a certain value of inductance.

In its simplest form an inductor consists of a number of turns of wire wound on a magnetic core. The winding is arranged so that the flux set up by the passage of varying or alternating current links the turns, and induces an e.m.f. which opposes the change in current.

20.5 INDUCTOR SYMBOLS. Examples of inductors and transformers are shown in in Fig. 72a. The general symbols for inductors and transformers are illustrated in Fig. 72b.

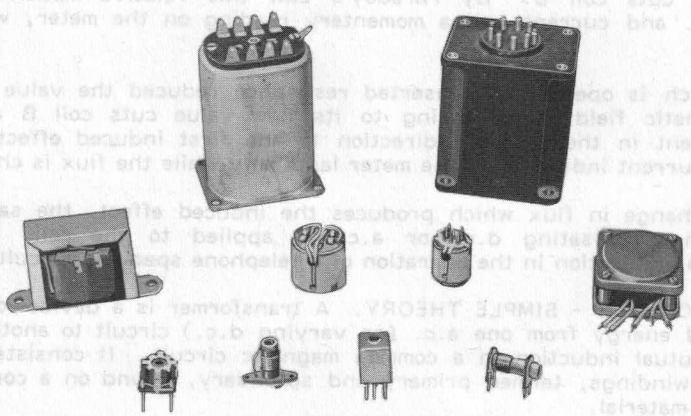


FIG. 72a. TYPICAL INDUCTORS AND TRANSFORMERS.

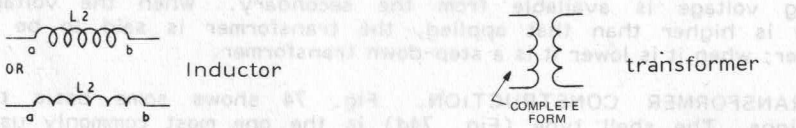


FIG. 72b. SYMBOLS

21. TRANSFORMERS.

21.1 MUTUAL INDUCTION. When an electromagnet is placed within a coil, and the current through it changed, an e.m.f. is induced in the coil without movement of the electromagnet.

When a current changing in one circuit, induces an e.m.f. in a neighbouring circuit, the effect is known as mutual induction, and it is upon this principle that a transformer operates.

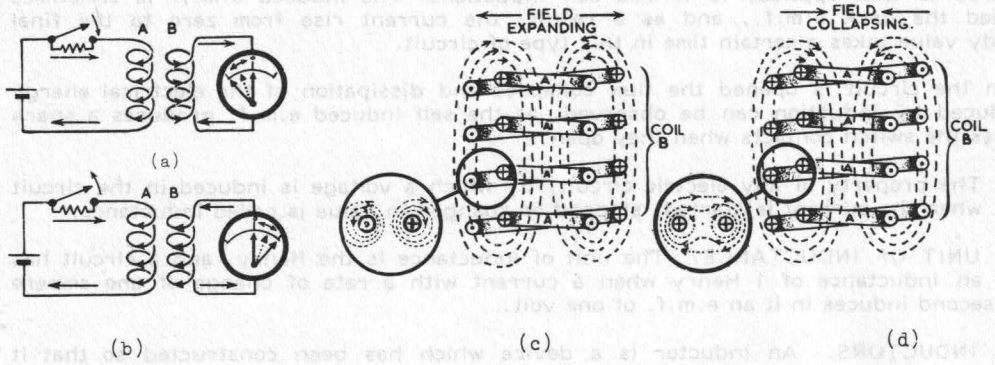


FIG. 73. INDUCING A CURRENT.

21.2 Two coils A and B are connected as shown in Fig. 73. When the switch is closed the current increases as the resistor across the switch contacts is short circuited. As a consequence, the existing magnetic field around coil A increases, and in expanding, cuts coil B. By Faraday's Law this relative motion results in an induced e.m.f. and current and a momentary reading on the meter, whilst the flux is changing.

When the switch is opened, the inserted resistance reduced the value of current in A. The magnetic field in collapsing to its new value cuts coil B and induces a transient current in the opposite direction to the first induced effect. Once again the transient current indicated by the meter lasts only while the flux is changing.

As it is the change in flux which produces the induced effect, the same results are achieved when a pulsating d.c. or a.c. is applied to the coil. The principle outlined has an application in the operation of a telephone speaking circuit.

21.3 TRANSFORMERS - SIMPLE THEORY. A transformer is a device for transferring electrical energy from one a.c. (or varying d.c.) circuit to another, using the principle of mutual induction in a common magnetic circuit. It consists essentially of two insulated windings, termed primary and secondary, wound on a core of laminated iron or similar material.

When an alternating (or varying) e.m.f. is applied to the primary, a higher or lower alternating voltage is available from the secondary. When the voltage at the secondary is higher than that applied, the transformer is said to be a step-up transformer; when it is lower it is a step-down transformer.

21.4 TRANSFORMER CONSTRUCTION. Fig. 74 shows some basic transformer designs. The shell type (Fig. 74d) is the one most commonly used, as its design is more efficient, with less magnetic losses than the other types shown.

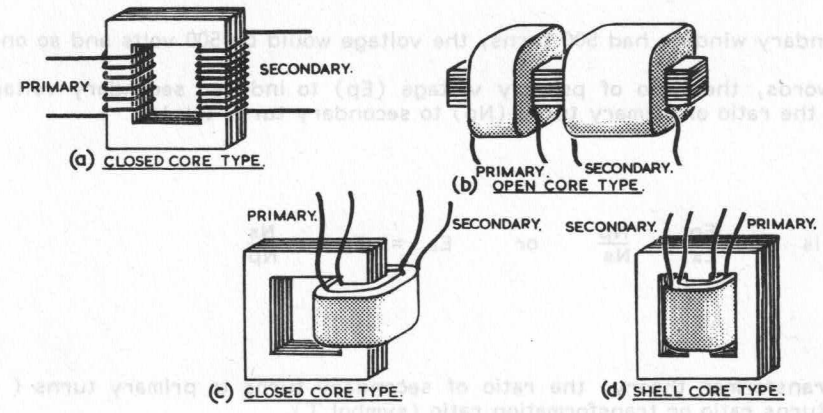


FIG. 74. TRANSFORMER CONSTRUCTION.

21.5 VOLTAGE TRANSFORMATION. Consider a transformer with 100 primary turns, and 200 secondary turns (Fig. 75).

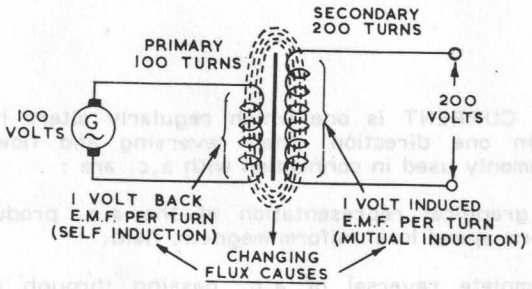


FIG. 75. STEP-UP TRANSFORMER.

An alternating potential of 100 volts is applied to the primary winding, and the secondary winding is left open circuit. Current flows in the primary winding and an alternating flux is established in the core. The flux links the turns of both windings inducing an e.m.f. of self induction in primary winding and an e.m.f. of mutual induction in the secondary winding.

In a well designed transformer, the voltage of self induction so closely approximates the applied e.m.f., that we can consider that the induced e.m.f. equals the applied e.m.f. We may assume then that the induced e.m.f. of the primary winding is 100 volts, that is, the magnetic field induces an alternating e.m.f. of 1 volt per turn in the primary winding, in opposition to the applied e.m.f.

In Fig. 75, the secondary winding is placed in such a manner that the flux produced by the primary winding links the turns of the secondary winding.

Now the flux, which is in this case inducing an e.m.f. of self induction of 1 volt per turn in the primary, winding is also linking the secondary and winding, therefore, will induce an e.m.f. of mutual induction (in the same direction as the induced e.m.f. of the primary) of 1 volt per turn in the secondary winding.

As the secondary winding has 200 turns, the voltage of mutual induction will be 200 volts.

If the secondary winding had 500 turns, the voltage would be 500 volts and so on.

In other words, the ratio of primary voltage (Ep) to induced secondary voltage (Es) is equal to the ratio of primary turns (Np) to secondary turns (Ns).

That is $\frac{Ep}{Es} = \frac{Np}{Ns}$ or $Es = Ep \times \frac{Ns}{Np}$

21.6 In transformer theory, the ratio of secondary turns to primary turns ($\frac{Ns}{Np}$) is called the turns ratio or transformation ratio (symbol T).

Thus, for voltage transformation:

$Es = T \times Ep$ where Ep = Primary voltage
Es = Secondary voltage
T = Turns ratio

22. A.C. THEORY.

22.1 ALTERNATING CURRENT is one which regularly alters its direction of flow, first flowing in one direction, then reversing and flowing in the opposite direction. Terms commonly used in connection with a.c. are :

:: Sine Wave. A graphical representation of the a.c. produced by a conductor rotating at uniform speed in a uniform magnetic field.

:: Cycle. One complete reversal of a.c. passing through a complete set of of positive and negative values.

:: Frequency. The number of cycles per second. Frequencies used in Telecom are expressed in Hertz (Abbreviation Hz).

The ways in which we use a.c. in Telecom are as follows :

:: Normal Telephone Conversations use a.c. to carry the message from one telephone to the other, over the telephone line.

:: Carrier Telephony uses a.c. as 'carriers' for a number of telephone conversations which can be transmitted over one line at the same time. The 'carrier' currents have different frequencies which allows them to be separated by the receiving equipment.

:: Carrier Telegraphy uses a.c. to provide a number of telegraph channels over one telephone line. The telegraph signals are in the form of pulses of a.c., the frequency of which is different for each channel thus preventing interference.

:: Radio, which includes broadcasting, radio telephone and television, uses high frequency alternating currents as carriers for the transmission of signals. We often hear radio stations announce their operating frequency.

22.2 In addition to these actual methods of communication, we use a.c. in other ways. Some of these are:

:: to ring telephone bells.

:: to provide the supervisory tones in automatic exchanges.

:: to operate exchange battery charging equipment.

:: to heat, light and ventilate buildings.

Alternating Currents used by Telecom vary in wave shape and frequency, and may come from many different sources. Some have pure sine wave form, but those used for the transmission of speech and music are more complex. The voltages producing these currents range from a few millivolts in the subscriber's telephone to many kilovolts in a radio transmitter.

22.3 VALUES OF ALTERNATING CURRENT AND VOLTAGE. During each cycle, an a.c. passes through a large range of values. They include:

:: Peak or Maximum Value. This is the maximum value occurring during one cycle. The peak value is not used as a direct indication of the effectiveness of an a.c. as this value is attained at two instants only during each cycle. However peak value is taken into consideration with regard to the insulation of high voltage circuits.

:: Instantaneous Value. This is the actual value of an a.c., at a certain instant or rotational degree position during a cycle.

:: Effective or R.M.S. Value. This is the value of a.c. which produces the same heating effect as a continuous current of the same amount. An a.c. of 10 amps (effective) has the same heating effect as 10 amps d.c.

:: Average Value. This is the average of all the instantaneous values of the a.c. for one half cycle. Average value is rarely used but it has application in electroplating and similar processes.

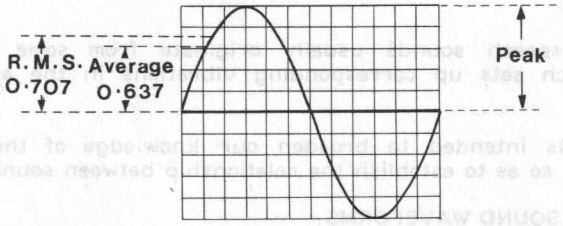


FIG. 76. VALUES OF ALTERNATING CURRENT AND VOLTAGES.

22.4 FREQUENCIES USED IN TELECOM. Frequencies are classified according to their use, and shown in Fig. 77. are :

:: Power frequency. A.C. at 50 Hz is distributed by Electricity Authorities and provides power for battery charging equipment and for normal lighting and power circuits in buildings.

:: Audio frequencies are those which produce sounds which can be heard by the human ear. They range from 16 Hz to 20 kHz, but the limits of hearing vary with different persons. Most people can hear sounds from 30 Hz to 15 kHz. In communications however, sufficient intelligence is available if equipment transmits voice frequencies within the range 300 Hz - 3.4 kHz.

:: Carrier frequencies are those used in carrier systems for transmitting simultaneous telephone messages over one pair of wires. The frequencies used with modern systems range from 6kHz to 12 MHz (approx.).

:: Radio frequencies are those which permit electric current to radiate appreciable electomagnetic energy, and are used for all forms of radio and television transmission. Radio Frequencies extend from about 30 kHz to approximately 8GHz.

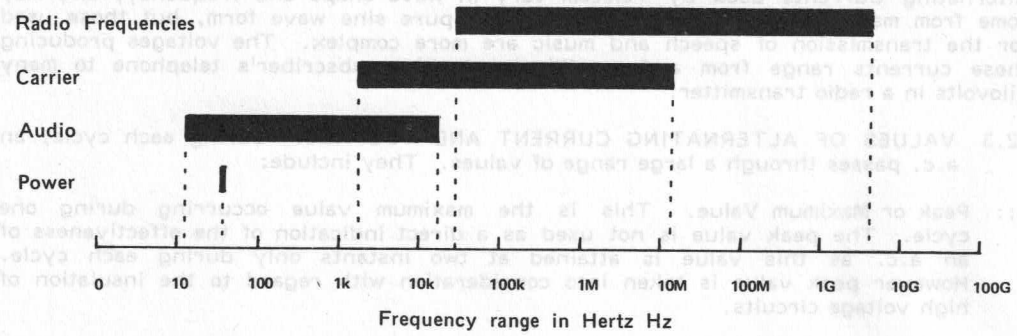


FIG. 77. FREQUENCIES USE BY TELECOM.

23. SOUND

23.1 Musical and speech sounds usually originate from some form of mechanical vibration, which sets up corresponding vibrations in the air and surrounding objects.

1.3 This section is intended to broaden our knowledge of the nature of sound, speech and hearing, so as to establish the relationship between sound and electricity.

23.2 ANALYSIS OF SOUND WAVEFORMS.

Sound waves can be divided into two types:-

:: Sine waves, which are the simplest form, and are referred to as a pure sound.

:: Non-sinusoidal or complex waves.

Very few sounds have the pure sine wave formation of a tuning fork vibration. Some typical waveforms are shown in Fig. 78. Although complex waveforms are not sinusoidal, they are regular, that is, each curve is repeated again and again. The difference between a musical note and a noise is that the musical note contains a repetition of a waveform but a noise has no recurring waveform.

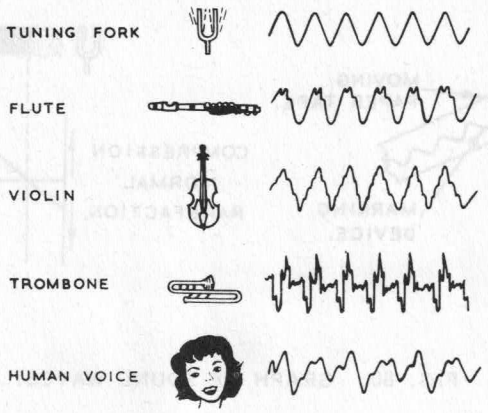


FIG. 78. SOME TYPICAL WAVEFORMS.

23.3 TRANSMITTING MEDIUM. Sounds are usually carried or transmitted from one point to another through the air, but they may be transmitted to varying degrees through any solid, liquid or gas. Unlike light and radiant heat, sound cannot be transmitted through a vacuum.

22.4 Using the tuning fork it is relatively simple to illustrate how sound is transmitted through air. When the fork is 'struck', the prongs vibrate rapidly and vary the air pressure in their immediate vicinity. This sets up, in the adjacent air particles, a series of alternate compressions (pressures greater than normal) and rarefactions (pressure less than normal) which travel outwards in all directions from the source.

In Fig. 79, the denser sections represent compression, and the lighter sections, rarefaction. For simplicity, only a narrow strip section is shown, but it is important to remember that all of the air surrounding the prongs is similarly affected.

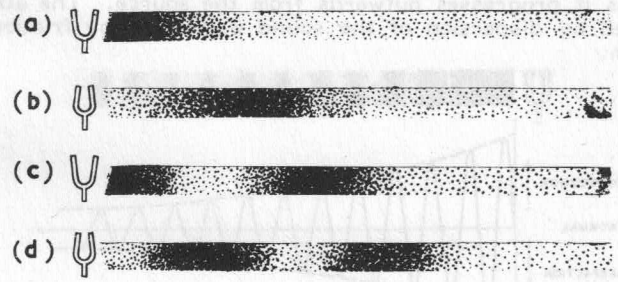


FIG. 79. TRANSMISSION OF SOUND.

23.5 GRAPHICAL REPRESENTATION. For convenience, sound vibrations are usually drawn as graphs. For example, if the vibrations of a tuning fork prong are traced on a moving paper tape (Fig. 80a), the trace is a sine curve, that is, the graph of the sine ratio of an angle as it varies from 0° through all angles to 360°. Similarly, the varying degrees of compression or rarefaction of the air particles may be indicated by a graph drawn above or below a reference line which represents the normal air pressure (Fig. 80b).

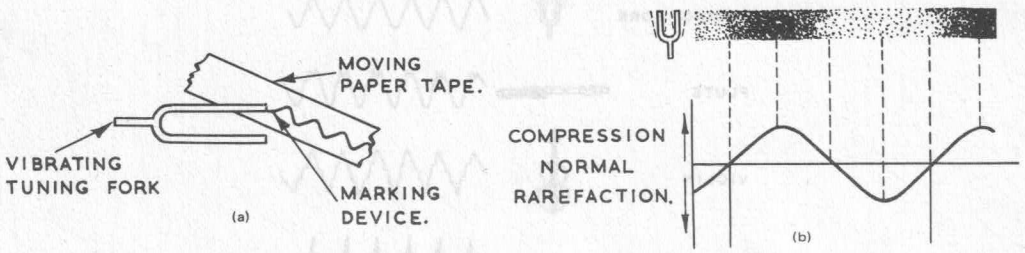


FIG. 80. GRAPH OF SOUND WAVES.

From the shape of these graphs, the term Sound Wave is applied to the successive compressions and rarefactions in the transmitting medium.

23.4 VELOCITY (OR SPEED). Examples of the velocity of sound are seen in everyday life. Thunder always follows lighting although both occur together at the source. The crack of a bat hitting a cricket ball is often heard after the hit is seen. The sound of an explosion takes some time to reach a distant observer.

The velocity of sound depends on the nature and temperature of the transmitting medium. For example:-

:: In air, the velocity is approximately 20 metres per second.

:: In water, the velocity is approximately 1,430 metres per second.

:: In solids, the velocity varies from 3500 - 5000 metres per second.

23.7 ATTENUATION. (Fig. 81). As the distance from the source of a sound is increased, the loudness (or amplitude of the sound wave) quickly decreases until the sound becomes inaudible. This effect is called Attenuation, and the sound is said to be attenuated as it progresses outwards from the source. The attenuation or loss of energy is caused by dispersion of the sound waves and by frictional losses in the transmitting medium.

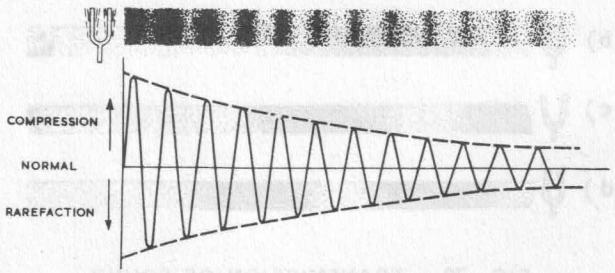


FIG. 81. ATTENUATION OF A SOUND WAVE.

23.8 REFLECTION AND ECHOES. When sound waves travelling through air strike an obstruction such as a wall, hill, etc., some of the sound continues to travel through the obstruction, and the remainder is reflected back. Thus, a person may often hear the same sound via the direct path and also the indirect or reflected paths. When heard separately from the direct sound, the reflected sounds are called echoes.

23.9 VOLUME, PITCH AND TIMBRE. Sound waves have three important characteristics:

:: Volume, that is, whether the sound is loud or soft.

:: Pitch, that is, whether the sound is high or low.

:: Timbre, or the distinctive quality of the sound.

23.10 THE VOLUME, LOUDNESS OR INTENSITY of a sound is determined by the amplitude of the vibrations made by the vibrating body. This effects the distance each particle of the transmitting medium is displaced from normal, or the extent to which the medium is compressed and rarefied above and below its normal value (see Fig. 82a).

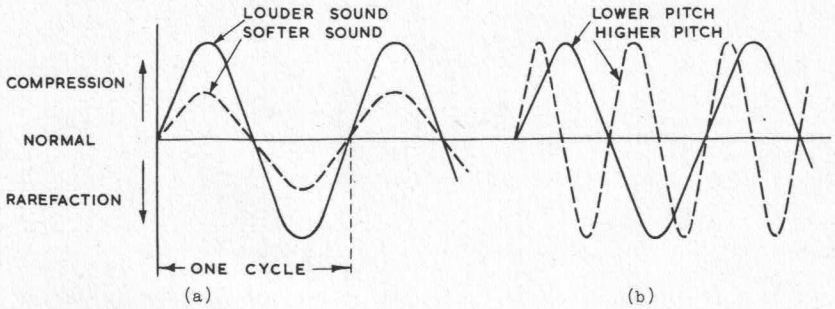


FIG. 82. SOUNDS OF DIFFERING VOLUME AND PITCH.

23.11 THE PITCH of a sound is determined by the number of vibrations per second made by the vibrating body, and, therefore, by the number of complete waves per second transmitted by that body (see Fig. 82b).

23.12 QUALITY OR TIMBRE (a French word meaning 'tone colour') is that characteristic which distinguishes sounds of the same pitch and volume.

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